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SUGGESTIONS REGARDING THE CLASSIFICATION OF THE IGNEOUS ROCKS

It may well be doubted if there is any science which presents greater difficulties to the teacher than that of systematic petrology—the classification of rocks. Even the name itself is seldom used, and appeals to the petrologist as almost a misnomer, because the science is so lacking in system, or, shall we say, overburdened by "systems." The German petrologists, under the leadership of Rosenbusch and Zirkel, and the French with Michel-Lévy at their head, are committed to the partial use of "systems" which are regarded as obsolete by their colleagues in other lands. The English and American schools of petrology have each their "systems" which differ from the German "systems" and more or less from each other. Yet as all are using essentially the same language of terms, the confusion which has arisen is so great that it is now necessary in employing a rock name to state at length what meaning the word is intended to convey.

Such a state of affairs is explainable on two grounds: first, the hesitancy felt in departing from the views held by the fathers of the science, and, second, the inherent difficulties which lie in the science itself, due to the complex nature of rocks.

The modern petrographical microscope, with its accessories, has introduced great refinement into the methods of study, so that descriptive petrology, or petrography, has become a very exact science. It is now possible to describe a rock in so many ways (in respect to so many of its attributes, such as mode of occurrence, texture, mineral composition, chemical composition, alterations, genesis, etc.,) that the difficulties in the way of bringing the results of the study into an orderly classification have been greatly increased. Nor is there reason to hope for any immediate remedy for this condition, since the largest and most representative body of petrologists ever assembled — the Seventh International Congress of Geologists, at St. Petersburg — was almost unanimous in the conviction that it would be useless to attempt to harmonize the nomenclature of the science by any early action of that body. The view was, however, expressed that something might be accomplished through the labors of a representative committee, which should, by frequent and careful deliberations, arrive at a tentative scheme for presentation to a future congress.

Undoubtedly the greatest obstacle in the way of reaching an understanding in the matter is that different values are assigned by different petrologists to the same attribute in rock classification. Some would lay greatest stress upon the mode of occurrence in the field; others would give the first place to mineral constitution, still others to texture, chemical composition, etc.

THE FIELD GEOLOGIST VS. THE PETROLOGIST

In deciding what shall be given first place as a basis in any system of rock classification, it should be realized, it seems to me, that the igneous rocks are not the sole property of the petrographer. The field geologist or the "naturalist," whatever be his special line of work, has need to make determination of igneous rocks, and he has a right to ask of the petrographer, who from his greater familiarity with rocks is charged with arranging them in an orderly system, such a classification that the geologist's determination in the field shall be *incomplete* rather

than *incorrect.* It should be made possible for the geologist to determine correctly at least the family to which a rock belongs, leaving to the petrographer the determination of rock species as well as the solution of the purely petrological problems.

To aid his eye the field geologist has only his pocket lens, and whatever rock species are fixed upon by petrologists they should be grouped into a comparatively small number of families, limited by simple and easily tested characteristics. In the case of the volcanic rocks it would be necessary to adopt terms broad enough to cover all rock types which it is found impossible to easily distinguish in the field. This reform would be made in the interest of the petrographer quite as much as of the geologist. If this be done the petrologist may multiply terms as he will to express any extension of his refined methods of study without in any way disturbing the composure or the effective work of the great body of field geologists.

BEARING OF RECENT PETROGRAPHICAL STUDIES ON ROCK CLASSIFICATION

From the point of view of the systematic petrologist the two most significant developments of petrology during the closing years of the nineteenth century have been, first, the numerous observations showing that the time honored families of igneous rocks, once supposed to be more or less sharply delimited, pass by insensible gradations into one another; and second, the return of chemical composition as a basis of rock classification to a position of prominence nearer to that which it formerly occupied.

The attention of petrologists was first drawn to the marked facial differentiation of a rock magma when the late Professor George H. Williams showed that rocks as diverse as quartz-mica-diorite and peridotite occur in the same stock near Peekskill, N. Y.[1] Since that time other investigators, but notably Iddings, Brögger, Ramsay, and Weed and Pirsson, have multiplied the

[1] G. H. WILLIAMS, The Gabbros and Diorites of the "Cortlandt Series," on the Hudson River near Peekskill, N. Y. Am. Jour. Sci. (3) XXXV, pp. 438–448, 1888.

observations of other but similar cases of magmatic differentiation. It is now the exception rather than the rule to discover an igneous rock mass of considerable dimensions in which some evidence of such gradations may not be observed.

The introduction of the petrographical microscope and its accessories, bringing as it did quick and delicate methods for determining the mineral constitution of a rock, naturally enough drew away the attention of petrographers from the slower and less brilliant methods of chemical analysis, which up to that time had been almost the only ones in use. Moreover most of the analyses of the period were, as we now know, inaccurate and failed to show the real chemical differences between individual rocks. The multiplication of the number of analyses and the improvements in the methods of rock analysis which have been made during the last decade, particularly by Hillebrand, have disclosed important differences among rocks formerly classed together, and thus necessitated a considerable elaboration of the systems of classification.

With this elaboration rock names have been introduced into the science with a rapidity which is little short of bewildering. The older petrological nomenclature was largely binomial or polynomial (*i. e.*, mica-syenite, quartz-mica-diorite) though the recent names seem planned for a monomial nomenclature (*i. e.*, ciminite). It is therefore not strange that misunderstanding has arisen in some quarters, where it is not realized that the new names proposed are for the most part specific and varietal in their nature and in no way to be correlated with the great family names such as granite or gabbro, and hence a protest has been made against what seems a needless overburdening of the science with names. Without entering upon this question here it may, I think, be stated with all assurance that some reforms are imperatively demanded before the worker will be fully equipped to discover the relationships among rocks because of the incubus of unclassified facts by which the science is now encumbered. Some of the particular reforms which to me seem desirable and practicable will be briefly described.

The definition of a rock as an object rather than as an integral part of the earth's crust.—The Wernerian conception of a rock as a geological unit or integral part of the earth's crust, still held by German petrologists, was adequate enough so long as rock masses were regarded as essentially homogeneous. With the discovery that such masses are usually quite heterogeneous and frequently represent not only several rock species but sometimes include almost the whole gamut of rock families, it became necessary to adopt some other definition. No other course seems open under these circumstances than to consider the individual rock specimen as the unit of classification and describe it primarily as an object, as is done with the units in the systems of other sciences.[1] If this is done it should be possible to *name* a rock from study of the specimen only though the *full description* would involve no less of field study than is undertaken when rocks are classified on the basis of their geological occurrence.

The importance of texture as a basis of classification.— All systems of classification of the igneous rocks emphasize more or less strongly rock texture as a basis of classification, for the reason that the texture is one of the properties of a rock most easily examined; and, further, because it is dependent so largely upon the peculiar conditions of rock consolidation or subsequent metamorphism. If rocks are described as objects this property of texture becomes inevitably of the very first importance.

The two main groups of the igneous rocks which are now generally recognized as distinguishable on the basis of texture are: first, those having a texture designated by Rosenbusch as *hypidiomorphic granular*, but which may in simpler language be referred to as *granitic*, the essential characteristic of which is that the mineral constituents by their manner of interlocking indicate for the rock in which they occur practically an uninterrupted period of crystallization; and, second, the *porphyritic*

[1] Cf. WHITMAN CROSS, The Geological *vs.* the Petrological Classification of Igneous Rocks. JOURN. GEOL. VI, p. 79, 1898. See also TEALL, British Petrography, p. 65.

texture in which the occurrence of two or more generations of the same constituent mineral indicates that the process of consolidation was not a continuous one but consisted of two or more stages.

The time honored but now obsolescent classification of igneous rocks on the basis of geological age has left us as a legacy a double nomenclature for the rocks of porphyritic texture, and this may be well illustrated by the terms "quartz porphyry" and "rhyolite" applied to rocks of porphyritic texture having a chemical composition similar to the granites. The former in its traditional, and also in its present German signification, refers to rocks of pre-Tertiary age, the latter to Tertiary or later rocks. The tendency of American petrographers seems to be to abandon entirely terms of the class of "quartz porphyry" and to extend the terms correlated with "rhyolite" to cover the rocks which were previously included in both groups. This tendency seems to me to be an unfortunate one since it results in classing together rocks which are essentially unlike. There may be no important difference between a particular "quartz porphyry" and a particular "rhyolite," but compare a drawer of hand specimens of the former with one of the latter and argument is unnecessary to show that as classes they are essentially different. The "quartz porphyries" are, as a class, devoid of vesicular and fluxion structures—they are in their mode of occurrence hypabyssal—and they more generally show the effects of devitrification, weathering, etc.

The "rhyolite" class of rocks may be conveniently distinguished from the "quartz porphyry" class by the possession of either vesicular or rhyolitic (fluxion) textures. Correspondence with some representative American petrographers has indicated to me that a restriction of the terms, rhyolite, trachyte, andesite, basalt, etc., to describe porphyritic types possessed of rhyolite or vesicular textures, would meet with considerable favor. Though of these terms rhyolite alone in its derivation calls attention to a fluxion texture, the others by their usage (trachytic structure, andesitic structure, etc.) have been given

the same significance. The terms, rhyolite-porphyry, trachyte-porphyry, andesite-porphyry, etc., by their substitution for the objectionable names, quartz-porphyry, quartzless porphyry, etc., would carry with them the idea of varietal rather than specific variation from the family type, and would, moreover, obviate the danger of their being interpreted in terms of the age classification.

Combination of chemical and mineralogical composition as a basis for rock classification.—Probably the majority of those petrologists who define rocks as objects would agree that chemical and mineralogical composition with texture should occupy the foremost places in rock classification.[1] It would probably be more satisfactory, were it practicable, to adopt chemical composition divorced from mineral composition as the primary basis in classification, but we are, per force, compelled to look first to the mineral composition, and work backward from this to the chemical composition—the chief factor in determining mineral composition. In the past the mineralogical examination of rocks has been largely qualitative, resulting, in some cases, in the classing together of rocks strikingly different as regards their ultimate chemical composition, but a stage has now been reached where such a method is no longer adequate. Pirsson has called attention to the necessity of paying greater regard to the relative quantities of the several essential constituents of a rock, thus making a rough estimation of its ultimate chemical composition.[2]

Specific, generic, and family rock names are applied to arbitrary rock types separated from one another by no sharp lines.—It follows, from the gradations generally observed to connect the families of the igneous rocks, that the names which we adopt to designate any individual rock, or class of rocks, is applied as a *type* name in the sense that it applies to a particular rock or collection of related

[1] Cf. TEALL: British Petrography, p. 69; WHITMAN CROSS: loc. cit., p. 80; J. P. IDDINGS: On Rock Classification, JOUR. GEOL., 1898, VI, p. 93; F. ZIRKEL: Lehrbuch der Petrographie, I, p. 829, 1893; W. C. BRÖGGER: Die Gesteine der Grorudit-Tinguait Serie, Christiania, 1894, p. 92.

[2] Igneous Rocks of Yogo Peak, Montana, Am. Jour Sci. (3) L, p. 478.

rocks, descriptions of which have been placed on record. The lines separating the several types are fixed arbitrarily, and would, in general, be located somewhat differently if undertaken at the outset by different individuals. For the types of larger order, these lines have been fixed by the traditional rock groups, and they are not likely to be much changed, but for the new and specific types they will be largely determined by the particular rock areas which are first examined.

A much more general use of intermediate family type names is inevitable, and terms like grano-diorite (or better, granito-diorite), trachy-andesite, etc., should be utilized.[1]

Rock relationships should be indicated by the combination of names into a binominal, or, if necessary, polynominal nomenclature.—The multiplication of specific terms, whose derivation has only a geographical signification (*e. g.*, Toscanite, Absarokite, Litchfieldite), furnishing not the slightest indication of the rock's relationships, is fast bringing petrologists to the condition of the Chinaman who is required to learn a unique syllable for every word in his language. Not possessing the admirable memory training of the Chinaman, the petrographer finds himself somewhat bewildered under the rain of new petrographical names which has characterized the closing years of the century. Many of these terms have been rendered necessary by the elaboration of the system of classification, due to the improved methods of chemical examination, and to the discovery of new petrographical provinces, and others are sure to be needed, but the enterprise in this branch of the science manifested in some quarters has sometimes provided us with two, or even three, names for the same specific rock type.

There can be no question that the nomenclature of petrography can be greatly simplified by a return to a binomial or polynomial nomenclature, which, fortunately, can be accomplished without much confusion, provided the old names of rock families be retained, together with compound names for the gradational types connecting them. An illustration may be

[1] Cf. BRÖGGER: op. cit., p. 93.

furnished by the interesting types, Toscanite, Vulsinite, and Ciminite, recently described by Washington.[1] They form together an intermediate family connecting the trachytes with the andesites, and called by Washington, trachy-dolerite, though it seems to me trachy-andesite is to be preferred. Trachy-dolerite-ciminite, or trachy-andesite-ciminite, is a term which tells at once that the rock to which it applies is a species of trachy-andesite which has been described from Monte Cimino. The term latite proposed by Ransome[2] for this group, while otherwise appropriate, fails to show the family relationships. Van Hise[3] has already suggested such a compounding of terms to express relationships. Certainly if the nomenclature of the science is to aid rather than to distract the worker some such reform from present conditions is demanded.

Graphical methods essential to a comprehensive study of rock analyses.—The necessity for studying the chemical composition in connection with the mineral composition of a rock requires that we examine in connection with one another the chemical analyses of all rocks having the same mineral constituents; or, better, those having the same constituents in the same relative quantities to a rough approximation. Such analyses show variations of one, two, or more per cent. in the quantities of some of the constituents for a single species or variety. But, on the other hand, differences of one or two per cent. in the amount of a constituent may be the cause of important differences in mineral composition or in other characteristics of the rock; hence it is important to know to that degree of precision the amount of each constituent which is present. For each analysis that would be remembered, it is necessary, then, to keep in the mind eight numbers of one or two figures each; and the student of petrology who would be familiar with the chemical nature of any

[1] H. S. WASHINGTON: Italian Petrological Sketches, No. 5, JOUR. GEOL., V, pp. 349–377, 1897.

[2] F. LESLIE RANSOME: Some Lava Flows of the Western Slope of the Sierra Nevada, Cal., Am. Jour. Sci. (4), V, p. 373, 1898.

[3] C. R. VAN HISE: The Naming of Rocks, JOUR. GEOL., VII, pp, 691–693, 1899.

given rock type must know the range in the percentages of the eight principal constituents. Moreover, he is not assisted in this by the knowledge that the upper and lower limits which he learns for a constituent of one species are at the same time, respectively, the lower and the upper limits for the same constituent in other allied species. A tax is thus imposed upon the memory far beyond what it may be reasonably expected to bear, and this tax is increased with the fixing of each new rock species.

The eye assists the mind not only to discover intricate relationships, but also to retain them, whenever the facts can be expressed by a definite form. This has been appreciated especially by the engineering profession, which has been accustomed, by the use of diagrams, to set forth in the most lucid manner facts which only the most laborious methods could otherwise bring out of the tables on which they are based. A curve contains the essence of pages of figures, and is readily carried in the mind owing to the large development of that faculty, which the Germans have so aptly termed *Vorschauungsgabe*. It is noteworthy that so little attempt has been made to apply graphic methods in petrology.

Recently, however, Iddings,[1] Becke,[2] Michel-Lévy[3] and Brögger[4] have each devised diagrams to illustrate rock analyses.

Of these the diagrams of Brögger seem to me the ones best adapted for general use because the simplest and the most characteristic. In the Brögger[5] diagram are set off on radius vectors the amounts of the eight principal chemical constituents reckoned

[1] J. P. IDDINGS: The Origin of the Igneous Rocks, Phil. Soc. of Washington. XII, pp. 89–214. Pl. II, 1892; Absarokite-shoshonite-banakite series. JOUR. GEOL., III, pp. 90–97, 1895; On Rock Classification, *ibid.*, VI, p. 92, 1898; Chemical and Mineralogical Relationships in Igneous Rocks, *ibid.*, p. 219.

[2] F. BECKE: Die Gesteine der Columbretes. TSCHERMAK'S min. u. petrog. Mittheil., VI, p. 315. 1897.

[3] M. MICHEL-LÉVY: Porphyr bleu de l'esterel, Bull. de la sèrvice de la carte géol. de la France. Tome IX, No. 57, 1897; Sur une nouveau mode de co-ordination des diagrammes representant les magmas des roches éruptifes. Bull. de la soc. géol. de la France. (3) XXVI, p. 311.

[4] W. C. BRÖGGER: Die Eruptivgesteine des Kristianiagebietes; Das Ganggefolge des Laurdalits. Kristiania, 1898, p. 255. Pl. I.

[5] Or LÉVY-BRÖGGER diagram.

in molecular ratios, ferrous and ferric iron being entered upon the same radius vector, and silica, because so much in excess of the others, being evenly divided between the two horizontal radius vectors. A broken line joining the intercepts on the eight radius vectors forms a polygon, which may be long and narrow, or short and thick, convex above or below, or reëntrant in any portion, left or right handed, etc., according to the chemical constitution of the rock.

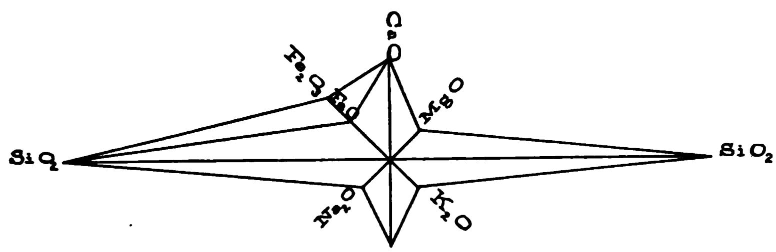


FIG. 1.

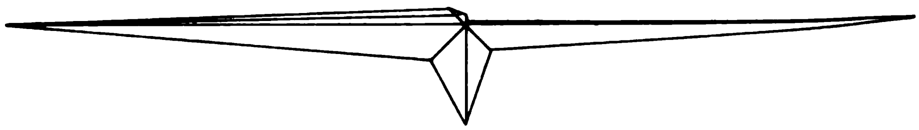
When viewed in this diagram, the rock comes to have a handwriting by which it may be instantly recognized. When drawn to scale, this diagram not only shows the chemical character of the rock but all the results of analysis may be quickly read from it numerically.[1] In it, as in all other successful diagrams the molecular ratio is substituted for the percentage of each constituent. Some authors now publish these ratios with every rock analysis. It is to be hoped that this will soon become a general custom.

THE COMPOSITE ROCK DIAGRAM

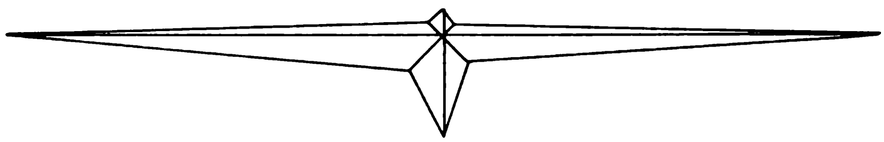
The principal objection to Brögger's diagram is that it represents not a rock species or a rock type but only an individual analysis, the rock type covering a considerable range of differing analyses. So far as I know, only isolated attempts have been made to average rock analyses to secure an adequate conception of the chemical constitution of the rock type, although the method of averaging results is so successfully used in other fields of science.

[1] On plates I, IV, V, and VI, .01 equals 1^{mm}.

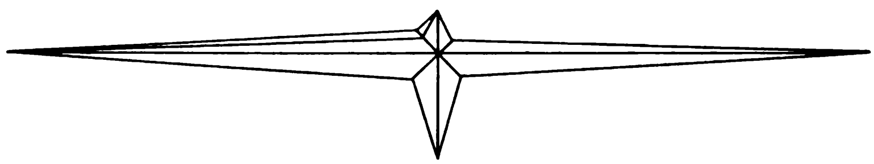
JOUR. GEOL., VOL. VIII, No. 1 **Plate I**



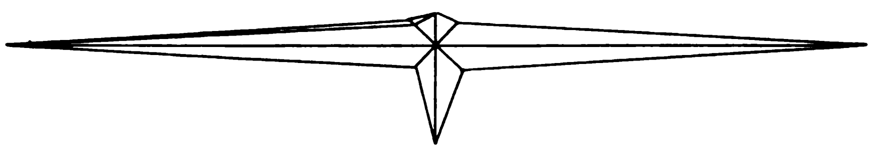
ALKALI GRANITE



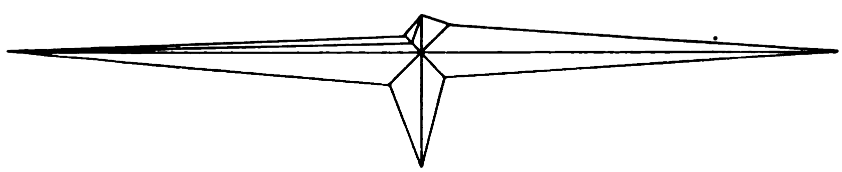
MUSCOVITE-BIOTITE GRANITE



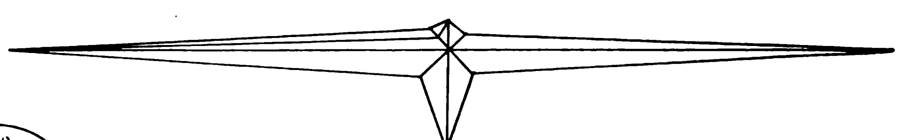
BIOTITE GRANITE



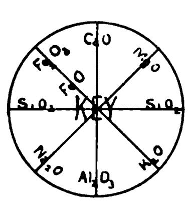
HORNBLENDE GRANITE



AUGITE GRANITE



GRANITE

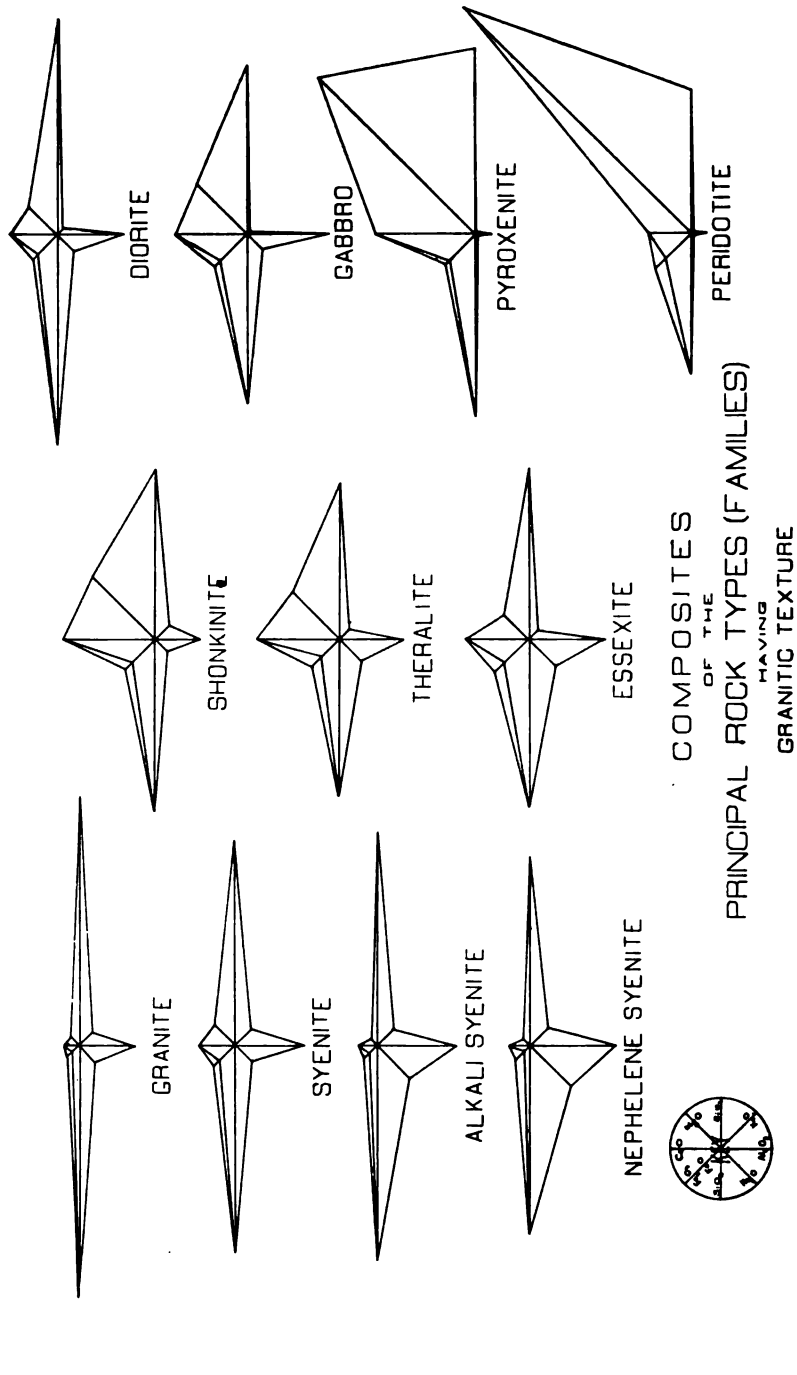


COMPOSITES

In connection with his class in petrology, the writer has for some time made use of diagrams which set forth the average composition of rock types. There are two ways in which such diagrams may be constructed. On the one hand, the diagram may be prepared after the same manner as composite photographs. The Brögger diagrams of a considerable number of representative rocks faintly outlined are superimposed upon the same radius vectors, so as to indicate the range in ratios of each constituent and in the darkest part of the figure the characteristics of the type. A composite diagram, better adapted for general use, because so much less intricate and so much easier to prepare, is obtained by first averaging the molecular ratios of each constituent for the group of analyses, and using the results to prepare a single diagram, which then becomes the diagram of a type instead of that of an individual.

The writer has so far modified the Brögger diagram as to draw the radius vectors so as to make equal angles with one another. The closed polygon obtained by connecting the intercepts on the different radius vectors has a form which changes in a marked degree to correspond with the changes in the length of any radius vector. Since the soda, potash, and alumina are all measured below the horizontal, acid rocks show diagrams stretched out along the horizontal and developed also below the horizontal; while the protoxide bases being all entered above the horizontal basic rocks are short and "fat above." Soda-rich or potash-rich rocks give respectively left-handed and right-handed diagrams, etc. All these facts the eye soon accustoms itself to take in at a glance and subconsciously, as it does in the case of handwriting. It is hardly necessary for the eye to estimate the lengths of the intercepts (a feat it is but poorly qualified to accomplish) for the ratios of the quantities of the constituents to one another is shown by the *angles of slope* of the polygonal sides — something which the eyes easily measures. The larger the number of correct and properly selected analyses which are utilized in obtaining the "composite" of any type, the greater is its value.

JOUR. GEOL., VOL. VIII, No. 1 Plate II



STUDY OF THE COMPOSITES OF THE PRINCIPAL FAMILY TYPES OF THE IGNEOUS ROCKS HAVING GRANITIC TEXTURE

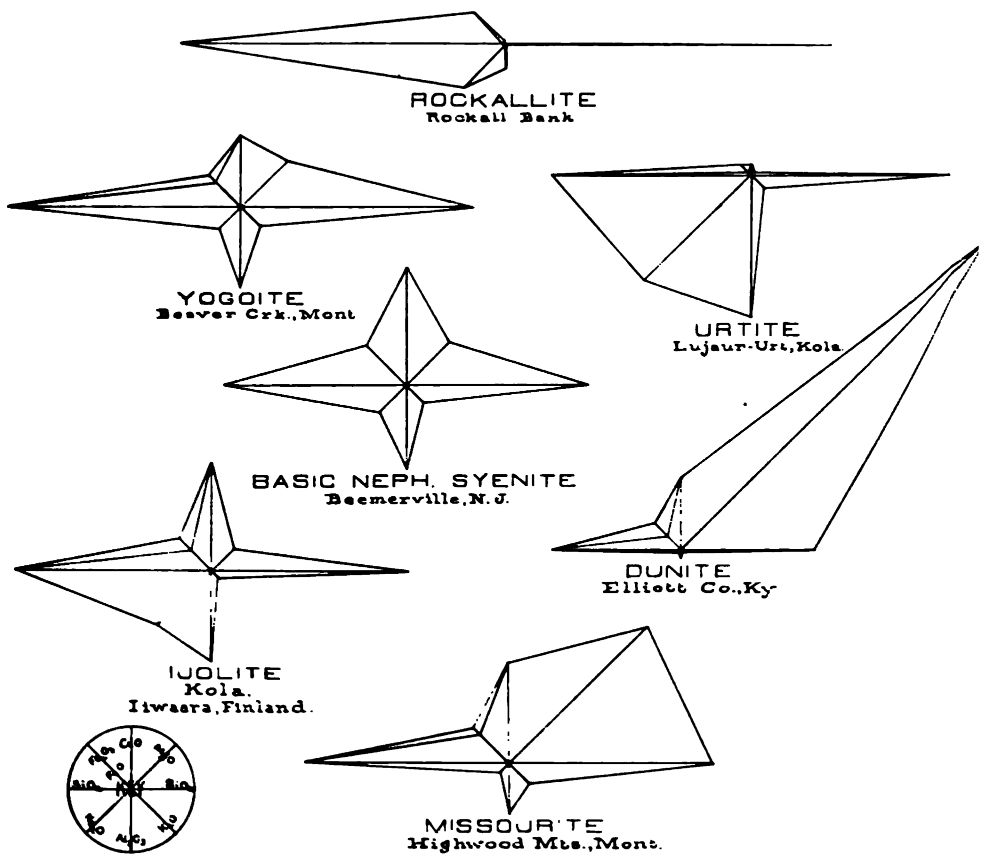
The composite diagram may be made to represent either specific or family types according to the analyses which are combined to produce it. By combining separately analyses of the principal species of granite, viz., alkali-granite, muscovite-biotite-granite, biotite-granite, hornblende-granite, and augite-granite, we are prepared to draw the composite diagram of each and can then compare them with one another; or, if we choose, we may compose all to form a single composite, which then represents not a specific but a family type—granite. These granite composites may be studied in Plate I. The alkali-granite composite is composed from six analyses, the muscovite-biotite-granite from two, the biotite, hornblende, and augite-granites each from four, so that the family composite is made from the average of twenty analyses.

The composites of each of the families of the igneous rocks having granitic textures may be similarly prepared and studied in connection with one another. (See Plate II). The family types selected, viz., granite, syenite, alkali-syenite, nephelene-syenite, shonkinite, theralite, essexite, diorite, gabbro (including hypersthene-gabbro and norite), pyroxenite, and peridotite, when seen in their composites allow their peculiar characteristics to be read at a glance.

The granites are distinguished from all the other families by their excess of silica and, moreover, by the small quantities of the protoxide bases and moderate amounts of alumina and the alkalies. *The granites, alkali-syenites, and nephelene-syenites form a progressive series which is characterized by decreasing silica and rapidly increasing soda and alumina, and to a less degree by increasing potash and lime, so that the alkali and nephelene-syenite rocks become preëminently the alkali-alumina rocks.*

The shonkonites, theralites, and essexites form a second progressive series in which the silica and iron remain nearly constant but in which the potash, magnesia, and lime steadily decrease as the soda and alumina increase. The essexites are essentially alkali-diorites

JOUR. GEOL., VOL. VIII, NO. 1 Plate III



SOME RARE ROCK TYPES
(GRANITIC TEXTURE)

distinguished from the diorites by a gain of alkalis, lime and iron, and a loss of silica.

The affinities of the syenites are seen to be entirely with the diorites and gabbros, with which they form a third progressive series which is continued imperfectly in the pyroxenites. In this series, characterized by generally decreasing silica and potash, the magnesia, lime, iron, and alumina increase, soda remaining practically constant throughout. The pyroxenites and peridotites, so poor in alkalis and alumina, show close affinity with each other and with the gabbros.

A few petrographical curiosities are represented in Plate III — rocks so exceptional in their occurrence as to be almost or quite unique. The first of these is Rockallite from Rockall Bank in the northeastern Atlantic,[1] a rock of granitic texture chemically closely related to the pantellerites of Fürstner (see Plate VII); Urtite is a nearly pure nephelene rock from the Kola peninsula[2] in arctic Russia which forms the limiting member of the nephelene-syenite family. Yogoite from Montana[3] is a "basic syenite." The "basic nephelene-syenite" from Beemerville, N. J.,[4] furnishes the most symmetrical of all the diagrams and gives indication of no near relationship to any other specific rock type though it is classed with the nephelene-syenites. The dunite from Elliott county, Kentucky[5] is so low in silica and so high in magnesia as to be very exceptional, though its diagram conforms to the general shape of the peridotite composite. Ijolite[6] and Missourite[7], the two recently

[1] JOHN W. JUDD: Notes on Rockall Island and Bank (Notice of Memoir) Geol. Mag., Dec., (4), VI, pp. 163–167, 1899.

[2] WILHELM RAMSAY: Urtit, ein basisches Endglied der Augitsyenit-Nephelinsyenit-Serie. Geol. Fören. Stockh. Förh., XVIII, pp. 459–468, 1896.

[3] WEED and PIRSSON: The Bearpaw Mountains of Montana, Am. Jour. Sci., (4), I, p. 357, 1896.

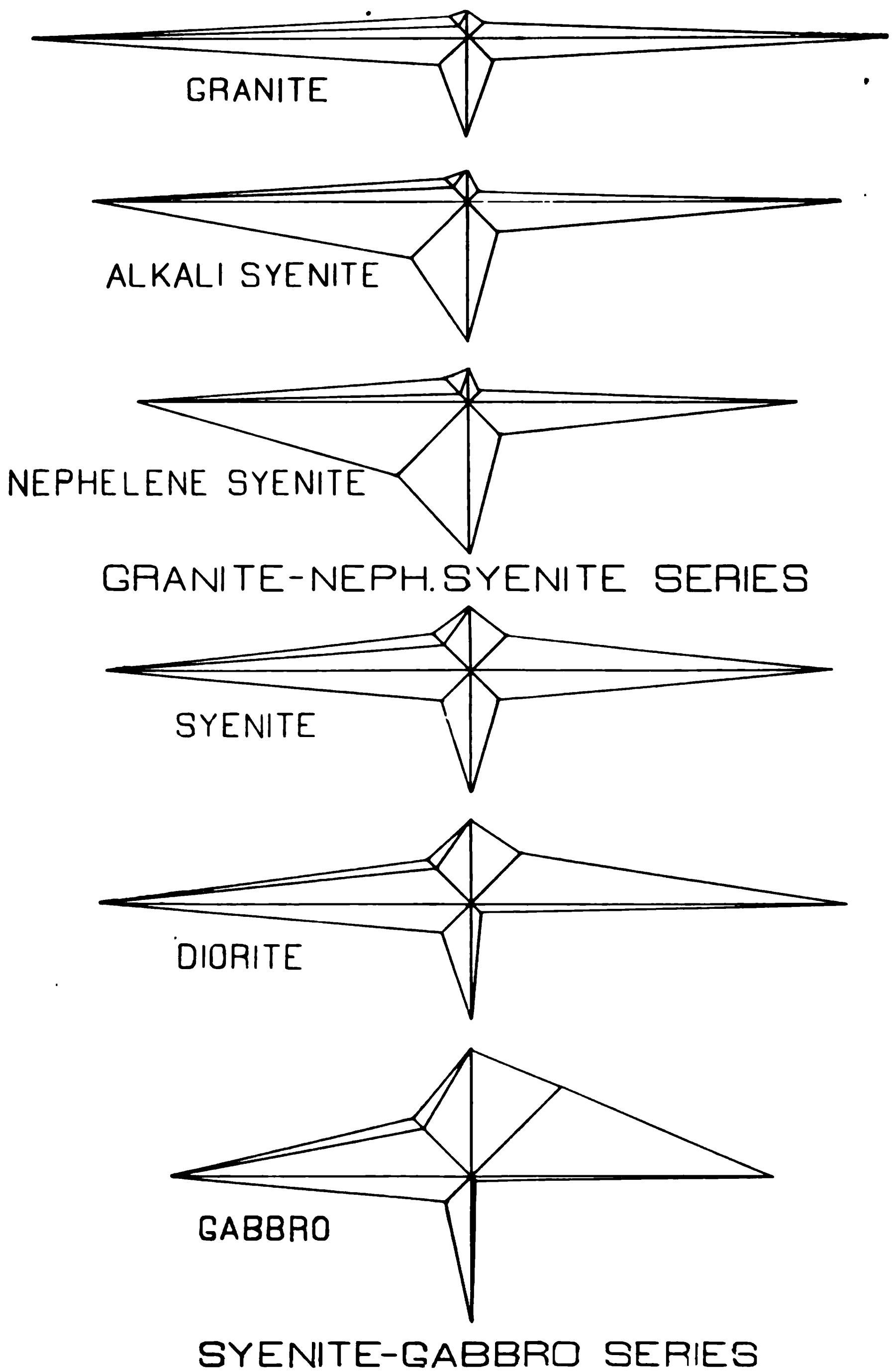
[4] J. F. KEMP: A basic Nephelene-syenite from Beemerville, N. J., N. Y. Acad. of Sci., XI, p. 68, 1892.

[5] J. S. DILLER: The Peridotite of Elliott County, Ky. Bull. No. 38, U. S. Geol. Survey, pp. 1–29, 1887.

[6] WILHELM RAMSAY: loc. cit.

[7] WEED and PIRSSON: Missourite, a New Leucite Rock from the Highwood Mountains of Montana. Am. Jour. of Sci., (4), II, pp. 315–325, 1896.

Jour. Geol., Vol. VIII, No. 1. Plate IV



described types for which Rosenbusch has named a new family[1] are certainly remarkable types, but except for the quantities of silica, iron, and lime which they contain, they are as different from one another as two rock types can be imagined to be. Ijolite is rich in soda and alumina, Missourite poor; Ijolite is poor in potash and magnesia, Missourite rich to excess in both. Comparison of their diagrams with those represented in Plate II shows that they are the end members of the Shonkinite-Essexite series, Missourite fitting almost perfectly into the series, being only a trifle low in lime, and Ijolite failing to do so only being too high in lime and a bit too low in iron.

The igneous rocks of granitic texture when examined chemically fall, therefore, quite naturally into three progressive series, which have distinct and common characteristics.—These series may provisionally be designated by the limiting families of each, as the granite nephelene-syenite, missourite-ijolite, and syenite-gabbro series (Plate IV). The peridotites and pyroxenites do not fall perfectly into any of the three, but are yet closely allied to the syenite-gabbro series.

Granite-nephelene-syenite series	Missourite-ijolite series	Syenite-gabbro series
Granite family	Missourite family	Syenite family
Alkali-syenite "	Shonkinite "	Diorite "
Nephelene-syenite "	Theralite "	Gabbro "
	Essexite "	———
	Ijolite "	Pyroxenite family
		Peridotite "

The composite diagrams of the granite-nephelene-syenite and syenite-gabbro series are shown in Plate IV, those of the Missourite-ijolite series in Plate V. The common characteristics of each of the series are well brought out by averaging the composites of the several members in each to form *series composites*, as has been done in Plate VI.

Composites of certain igneous rock types having rhyolitic texture.—No comprehensive attempt has yet been made to determine similar relationships among the rocks of rhyolitic texture, but composites of a considerable number of the specific rock types of

[1] ROSENBUSCH: Elemente der Gesteinslehre, p. 179.

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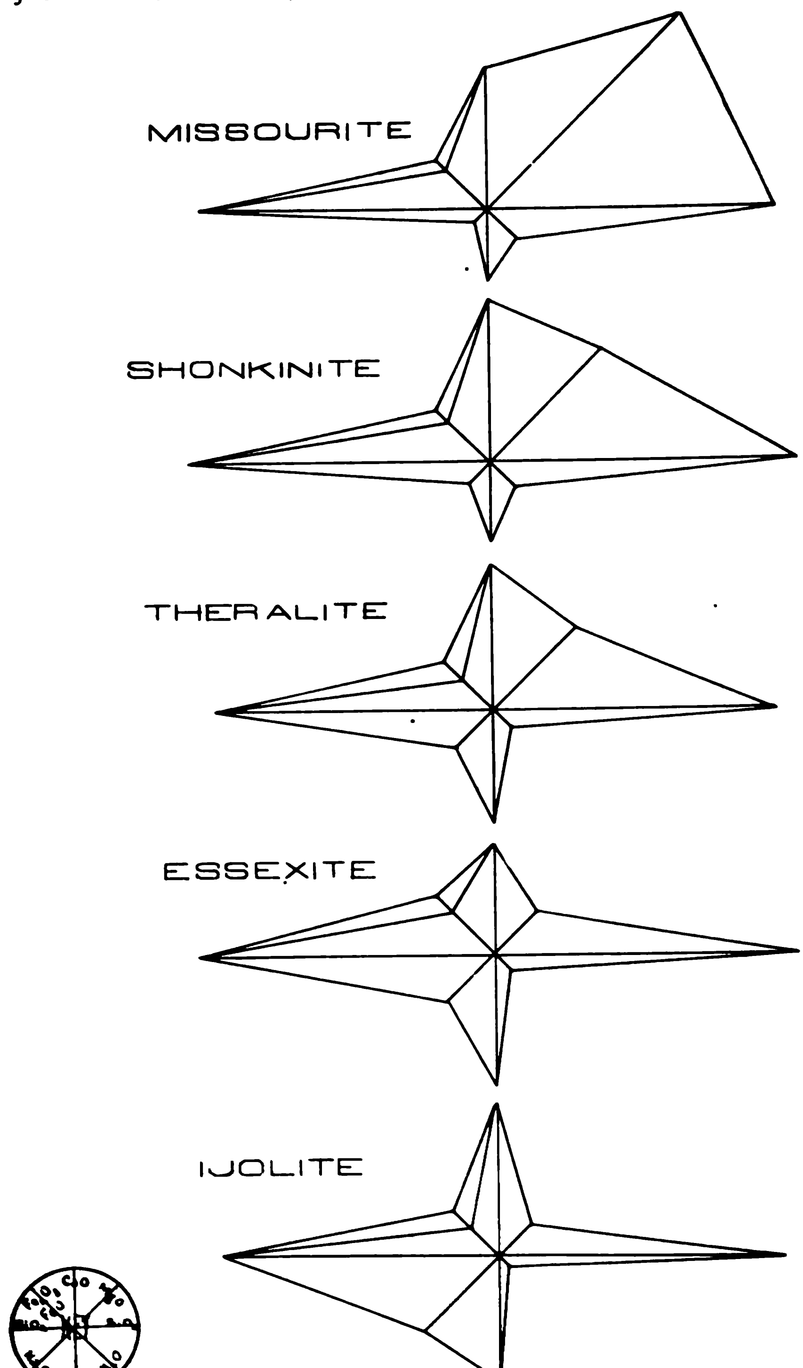
Plate V



MISSOURITE-IJOLITE SERIES

cid and intermediate composition have been prepared. Plate VII isplays together the composite diagrams of the specific types elonging to the families which Washington[1] has designated as he trachyte, trachy-andesite, trachy-dolerite, and andesite series.

The rhyolite diagram is a composite of nine analyses of hyolites from Hungary, Ponza, the Auvergne, Nevada, and olorado. The soda-rhyolite composite is compounded from ix analyses, mainly of Wisconsin rocks soon to be described by . K. Leith and the writer. The four pantellerites which furnish he pantellerite diagram are from the island of Pantelleria. The rachytes, six in number, are those of the Auvergne, Ischia, the ifel, the Bohemian Mittelgebirge, and Monte Amiata; and he two domites were from the Auvergne. The vulcanite diaram is not a composite but an individual rock diagram made rom the type analysis from Vulcano. The six dacite analyses omposed were of rocks from Columbia, Guatemala, Lassen's eak, Cal., and McClellan Peak, Nev., while the seven andesite nalyses used in preparing the andesite composite were of mica-nd hornblende-andesites from the Eureka district, Nev.; Custer ounty, Col.; Cartagena, Spain; the Siebengebirge on the Rhine; anama; and Columbia. The Toscanite, Vulsinite, and Ciminite nalyses are the Italian ones given by Washington,[2] and were espectively ten, ten, and eleven in number. The Banakites, hoshonites, and Absarokites represented in the analyses are hose described by Iddings[3] from the Yellowstone National Park nd numbered four, five, and five respectively.

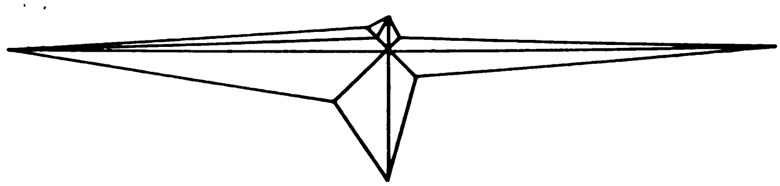
These *specific* composites are much less interesting as indiating relationships than the composites of a higher order would e, but they are here introduced to show that the composite iagram is capable of bringing out the chemical characteristics f rocks which differ only slightly from one another, as well as he characteristics of different families.

[1] H. S. WASHINGTON: Italian Petrological Sketches, V. JOUR. GEOL., V, p. 366. 897.

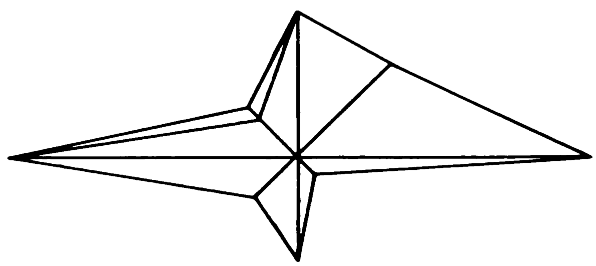
[2] H. S. WASHINGTON: loc. cit.

[3] J. P. IDDINGS: Absarokite-Shoshonite-Banakite series, JOUR. GEOL., III, pp. 935–59, 1895.

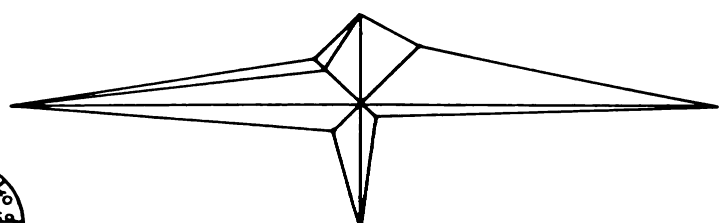
JOUR. GEOL., VOL. VIII, No. 1 Plate VI

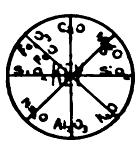


GRANITE-NEPH. SYENITE SERIES



MISSOURITE-IJOLITE SERIES

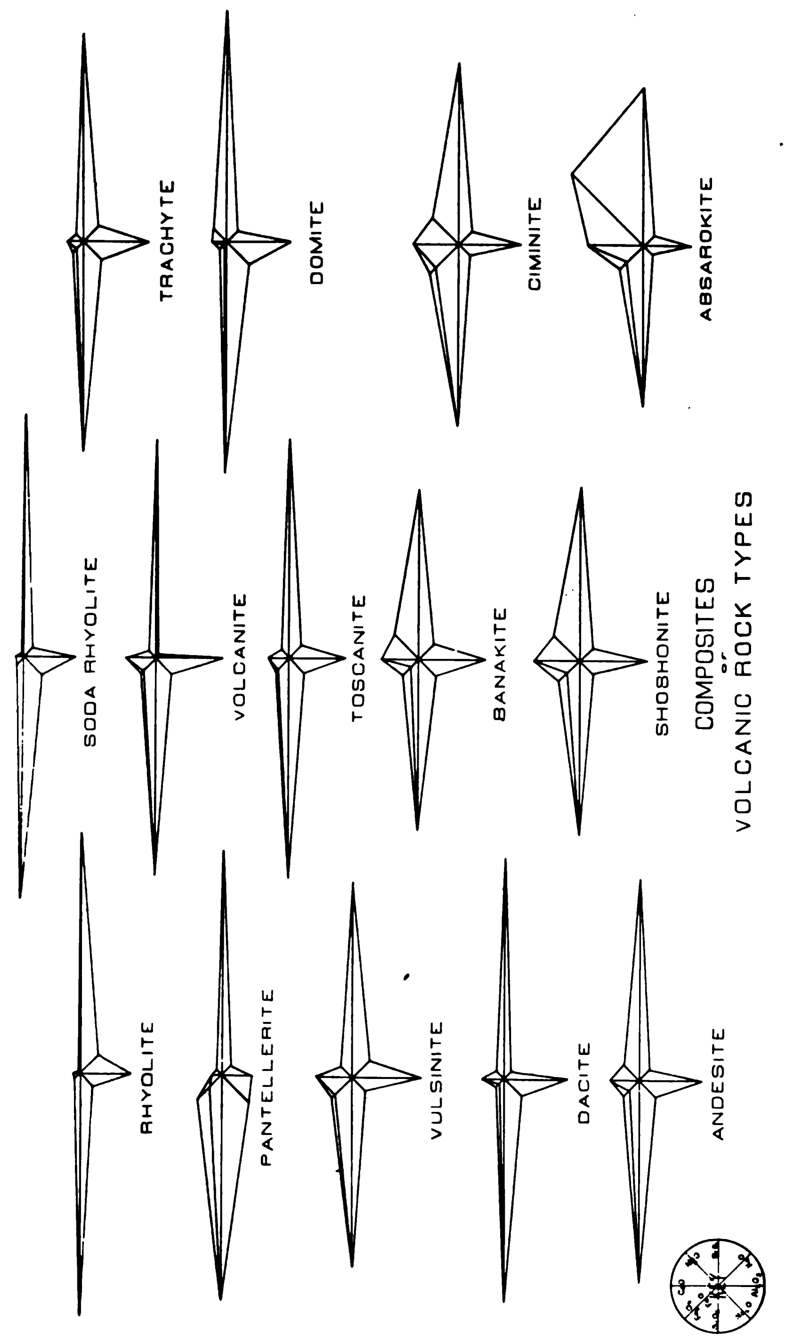




SYENITE-GABBRO SERIES

SERIES COMPOSITES

JOUR. GEOL., VOL. VIII, NO. 1 Plate VII



In conclusion, I would suggest to all persons publishing analyses of rocks the advisability of printing beneath the figures showing the percentage, composition, the corresponding molecular ratios, and further, that the arrangement of oxides in the analysis be for the sake of uniformity that which has been consistently followed by Rosenbusch, Washington, and some others, and which is here used in the composite tables showing the averaging of analyses for the composite diagrams. The principal deviation from this order which I have observed is an inversion of the order of magnesia and lime or of soda and potash, which can hardly be regarded as essential. If these suggestions be followed, the work of those who examine rock analyses will be materially lightened and the liability to error in transcribing will be lessened.

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ROCKS WHOSE ANALYSES HAVE BEEN COMBINED TO PRODUCE THE COMPOSITES OF THE GRANITIC-TEXTURED IGNEOUS ROCKS

The greater number of the analyses of these rocks are to be found either in the tables of Rosenbusch's *Elemente der Gesteinslehre*, published in 1898 (abbreviation R), or in Clarke and Hillebrand's *Analyses of Rocks and Analytical Methods*,[1] published in 1897 (abbreviation C and H).

GRANITE[2]

1. Alkali-granite, Drammen, Norway.
2. Alkali-granite, Sandsvar, "
3. Alkali-granite, Pelvoux, Dauphinée, France.
4. Alkali-granite, Hardwick quarry, Quincy, Mass., Am. Jour. Sci. (4), 6, p. 181.
5. Alkali-granite, Montello, Wis., Hobbs and Leith. To be described in a forthcoming bulletin of the Geol. and Nat. Hist. Survey of Wisconsin.
6. Alkali-granite, Waushara Co., Wis., Bull. No. 3, Wis. Geol. and Nat. History Survey, 1898, p. 2.
7. Muscovite-biotite granite, Hautzenberg, Bayerischer Wald, Germany.
8. Muscovite-biotite granite, Katzenfels, Graslitz, Erzgebirge, Bohemia.

[1] Bull. 148, U. S. Geol. Surv.

[2] All the granite analyses with the exception of certain of the alkali granites are selected from Rosenbusch's list, on page 78 of the work cited.

9. Biotite-granite, Bobritzsch, Freiberg, Saxony.
10. Biotite-granite, Barr, Alsace.
11. Biotite-granite, Durbach, Black Forest, Baden.
12. Biotite-granite, Melibocus, Odenwald, Hesse.
13. Hornblende-granite, Mariposa Co., Nevada.
14. Hornblende-granite, Pré de Fauchon, Vosges.
15. Hornblende-granite, Syene, Egypt.
16. Hornblende-granite, ("Rapakiwi granite"), Finland.
17. Augite-granite, Laveline, Vogesen.
18. Augite-granite, Oberbruch, Dollerenthal, Alsace.
19. Augite-granite, Kekequabic Lake, Minn.
20. Augite-granite, Birkrem, Ekersund, Norway.

ALKALI-SYENITE

1. Nordmarkite, Tonsenaas, near Christiania, Norway. R. p. 112.
2. Pulaskite, Fourche Mt., Arkansas. *Ibid.*
3. Umptekite, Umpjaur, Kola Peninsula, Russia. *Ibid.*
4. Laurvikite, Laurvik, Norway. *Ibid.*
5. Sodalite-Syenite, Square Butte, Mont. *Ibid.*

NEPHELENE-SYENITE

1. Nephelene-Syenite, Salem Neck, Mass. Jour. Geol. **8**, p. 803.
2. Nephelene-Syenite, Great Haste Island, Mass. *Ibid.*
3. Litchfieldite, Litchfield, Maine. C. & H., p. 65.
4. Nephelene-Syenite, Red Hill, N. H. C. & H., p. 67.
5. Nephelene-Syenite, Fourche Mt., Arkansas. Igneous Rocks of Ark., p. 88.
6. Lujaurite, Umptek, Kola Peninsula, Russia. R. p. 126.
7. Nephelene-Syenite, Beemerville, N. J. C. & H., p. 80.
8. Basic Nephelene Syenite, Beemerville, N. J. N. Y. Acad. Sci. **11**, p. 68.
9. Nephelene-Syenite, Saõ Paolo, Brazil. R. 126.
10. Laurdalite, Lunde, Norway. Zeitsch. f. Kryst. **16**, p. 33.
11. Sodalite-Syenite, Kangersluarsuk, Greenland. R. p. 126.
12. Urtite, Lujaur Urt, Kola Peninsula, Russia. *Ibid.*
13. Leucite-Syenite, Magnet Cove, Ark. *Ibid.*
14. Borolanite, Lake Borolan, Scotland. *Ibid.*

MISSOURITE-IJOLITE SERIES

Missourite

1. Missourite, Shonkin Creek, Highwood Mts., Mont. C. & H. 154.

Shonkinite

1. Shonkinite, Beaver Creek, Bearpaw Mts., Mont. C. & H. p. 149.
2. Shonkinite, Yogo Peak, Little Belt Mts., Mont. *Ibid.*

3. Shonkinite, Square Butte, Highwood Mts., Mont. R. p. 176.
4. Shonkinite, Monzoni, Tyrol. Zeitsch. d. d. geol. Gesell. 24, p. 201.
5. Nephelene-Pyroxene-Malignite, Poobah Lake, Canada. R. p. 176.

Theralite

1. Theralite, Gordon's Butte, Crazy Mts., Mont. R. p. 176.
2. Theralite, Martinsdale, Crazy Mts., Mont. *Ibid.*
3. Theralite, Umptek, Kola Peninsula, Russia. *Ibid.*

Essexite

1. Essexite, Salem Neck, Mass., Jour. Geol., 7, p. 57.
2. Essexite, Salem Neck, Mass. R. p. 172.
3. Essexite, Isla de Cabo Fria, Rio de Janeiro, Brazil. *Ibid.*
4. Essexite, Mt. Fairview, Custer Co., Colo. *Ibid.*
5. Essexite, Rongstock, Bohemia. *Ibid.*

Ijolite

1. Ijolite, Iiwaara, Finland. R. 180.
2. Ijolite, Kaljokthal, Umptek, Kola Peninsula, Russia. *Ibid.*

SYENITE-GABBRO SERIES

Syenite

1. Mica-Syenite Frohnau, Black Forest, Baden. R. p. 106.
2. Mica-Hornblende Syenite, Silver Cliff, Colo. C. & H., p. 169.
3. Hornblende-Syenite, Plauenscher Grund, Saxony. R. p. 106.
4. Hornblende-Syenite, Biella, Piedmont. *Ibid.*
5. Monzonite, Monzoni, Tyrol. R. p. 109.
6. Monzonite, Yogo Peak, Mont. C. & H. p. 147.
7. Yogoite, Beaver Creek, Bearpaw Mts., Mont. C. & H. p. 156.
8. Akerite, Thingshoug, Norway. R. p. 111.

Diorite

1. Tonalite, Adamello, Tyrol. R. p. 140.
2. Banatite, Dognacska, Banat, Austro-Hungary. *Ibid.*
3. Grano-diorite, near Bangor, Butte Co., Cal. C. & H. p. 204.
4. Diorite, Elk Mts., Colo., C. & H. p. 177.
5. Diorite, Electric Peak, Yellowstone National Park. C. & H. p. 117.
6. Amphibole-Diorite, Electric Peak, Yellowstone National Park C. & H. p. 118.
7. Augite-Diorite, Electric Peak, Yellowstone National Park. C. & H. p. 117.
8. Augite-Diorite, Peach's Neck, Mass. Jour. Geol. 7, p. 60.
9. Diorite, Schwarzenberg, Vogesen. R. p. 140.

Gabbro

1. Anorthosite, Nain, Labrador. Zeitsch. d. d. geol. Gesell. 1884.
2. Orthoclose-Gabbro, Duluth, Minn. Neues Jahrb. f. Min. 1876, p. 117.
3. Gabbro, Northwestern Minn. C. & H. p. 112.
4. Garnetiferous Gabbro, Granite Falls, Minn. C. & H. p. 113.
5. Gabbro, Nahant, Mass. Jour. Geol. 7, p. 63.
6. Hypersthene-Gabbro, Baltimore, Md. Bull. U. S. Geol. Survey, No. 28, p. 39.
7. Norite, Montrose Point, Hudson River, N. Y. Am. Jour. Sci. (3) **22**, p. 104.
8. Norite, Ivrea, Piedmont. R. p. 151.
9. Forellenstein, Neurode, Silesia. *Ibid.*
10. Forellenstein, Coverack, Cornwall. *Ibid.*

ULTRA-BASIC ROCKS

Pyroxenite

1. Websterite, Webster, N. C. C. & H. p. 92.
2. Bronzite-Diallage Rock, Hebbville, Md. C. & H. p. 84.
3. Hornblende-Hypersthene Rock, Gallatin Co., Mont. C. & H. p. 140.
4. Websterite, Johnny Cake Road, Md. R. p. 165.

Peridotite

1. Mica-Peridotite, Crittenden Co., Ky. C. & H. p. 94.
2. Scyelite, Achavarasdale Moor, Caithness. Quart. Jour. Geol. Soc. **41**, p. 402.
3. Wehrlite, Red Bluff, Gallatin Co., Mont. C. & H. p. 140.
4. Lherzolite, Johnny Cake Road, Baltimore Co., Md. R. 165.
5. Saxonite, Douglas Co., Oregon. C. & H. p. 231.
6. Cortlandtite (Schillerfels) Schriesheim, Odenwald, Hesse. R. p. 165.
7. Bronzite Diallage Peridotite, Howardville, Md. Bull. U. S. Geol. Survey, No. 28, p. 54.
8. Dunite, Dun Mts., New Zealand. R. p. 165.
9. Dunite, Elliott Co., Ky. C. & H. p. 93.

Rare Rock Types

1. Rockallite, Rockall Bank, Atlantic. Geol. Mag. (4) **6**, p. 165. 1899.
2. Basic Nephelene-Syenite, Beemerville, N. J. Trans. N. Y. Acad. Sci. **11**, p. 86.
3. Urtite, Lujaur Urt, Kola Peninsula, Russia. Geol. Fören, Förh, **18**, p. 462. 1896.
4. Ijolite, Iiwaara, Finland, and Umptek, Kola Peninsula, Russia. *Ibid.* **13**, p. 300. 1891.
5. Missourite, Highwood Mts., Mont. Am. Jour. Sci. (4) **2**, p. 315. 1896.
6. Dunite, Elliott Co., Ky. Bull. 38 U. S. Geol. Survey, p. 24. 1887.

COMPOSITES OF IGNEOUS ROCK TYPES OF GRANITIC TEXTURE

	Species of granite					Families of granite-neph.-syenite series			
	Alkali granite (6)	Muscovite-biotite granite (2)	Biotite granite (4)	Hornblende granite (4)	Augite granite (4)	Granite (20)	Alkali syenite (5)	Nepheline-syenite (14)	Composite
SiO_2	74.07 1.226	70.49 1.165	69.43 1.149	69.32 1.147	66.08 1.094	69.88 1.157	60.62 1.004	53.47 .885	61.32 1.015
TiO_2	......	.33	.44	.31	.17	.31	.35	.26	.31
Al_2O_3 ...	13.48 .131	13.77 .135	14.54 .142	13.37 .131	15.81 .155	14.19 .139	19.13 .187	20.87 .204	18.06 .176
Fe_2O_3 ...	1.86 .012	3.69 .024	1.55 .010	1.40 .009	2.12 .013	2.12 .013 } 3.68	2.57 .017 } 4.66	4.93 .031 } 6.20	3.21 .020
FeO	1.29 .018	.02 .000	2.23 .031	2.97 .041	1.30 .018	1.56 .022	2.09 .028	1.27 .018	1.64 .023
MnO.....	......	......	.12	......	......	.02	.10	.07	.06
MgO	.16 .004	.87 .020	.96 .024	1.55 .039	2.17 .050	1.14 .028	.74 .018	.85 .021	.91 .023
CaO.....	.76 .012	1.78 .032	2.94 .053	2.38 .043	2.61 .046	2.09 .037	2.38 .042	2.70 .048	2.39 .043
Na_2O....	4.24 .068	3.82 .062	3.47 .048	2.84 .040	4.36 .061	3.75 .060	6.45 .104	8.26 .133	6.15 .099
K_2O	4.35 .046	4.36 .046	3.91 .042	4.30 .046	4.30 .046	4.24 .045	5.19 .054	5.55 .059	4.99 .053
H_2O	.63	.35	.66	.95	.61	.64	.90	1.32	.95
Others...	......	.18	.05	.50	......	.15	.23	.32	.23
Total ..	100.04	99.66	100.30	99.89	99.53	100.09	100.75	99.87	100.22

COMPOSITES OF IGNEOUS ROCK TYPES OF GRANITIC TEXTURE (*Continued*)

	Families of missourite-ijolite series						Families of syenite-gabbro series			
	Missourite (1)	Shonkinite (5)	Theralite (3)	Essexite (5)	Ijolite (2)	Composite	Syenite (8)	Diorite (9)	Gabbro (10)	Composite
SiO_2....	46.06 .762	48.80 .808	44.67 .740	47.91 .793	44.71 .740	46.43 .769	58.73 .972	60.23 .997	48.40 .801	55.79 .924
TiO_2....	.73	.59	1.00	1.35	1.41	1.02	.65	.58	.61	.58
Al_2O_3...	10.01 .098	11.13 .108	15.58 .151	17.82 .174	17.46 .170	14.40 .141	16.78 .164	16.14 .158	20.06 .196	17.66 .172
Fe_2O_3...	3.17 .019	3.68 .023	5.28 .033	5.38 .030	5.15 .032	4.53 .022	3.05 .019	2.69 .017	2.99 .019	2.91 .018
FeO.....	5.61 .078 } 8.78	5.48 .076 } 9.16	4.85 .067 } 10.13	5.68 .079 } 11.06	3.71 .052 } 8.86	5.07 .070	3.79 .052 } 6.84	4.51 .063 } 7.20	6.40 .089 } 9.39	4.90 .068
MnO....	......	.07	.11	.02	.20	.08	.14	.02	.04	.07
MgO....	14.74 .364	8.41 .210	6.31 .158	3.26 .081	2.67 .060	7.08 .177	2.77 .069	3.62 .090	6.73 .168	4.37 .109
CaO.....	10.55 .189	12.07 .216	11.05 .197	8.29 .148	11.50 .205	10.69 .191	4.82 .086	6.21 .111	9.38 .168	6.80 .121
Na_2O....	1.31 .021	2.33 .038	5.03 .071	5.45 .088	8.73 .141	4.57 .074	3.29 .053	3.40 .055	2.83 .045	3.17 .051
K_2O....	5.14 .053	4.54 .047	3.10 .033	2.81 .030	1.82 .019	3.48 .036	4.96 .053	1.74 .019	.88 .009	2.53 .026
H_2O....	1.44	1.31	2.36	1.14	.67	1.38	.96	.58	1.84	1.13
Others...	.81	1.80	.31	.86	.85	.93	.46	.22	.02	.23
Total..	99.57	100.09	99.66	99.97	98.88	99.66	100.40	99.94	100.18	100.14

ULTRA-BASIC COMPOSITES

	Pyroxenite (4)	Peridotite (9)
SiO_2	52.58 .871	40.58 .672
TiO_2	.11	.77
Al_2O_3 ...	3.69 .036	3.64 .035
Fe_2O_3 ...	1.90 .012	5.89 .037
FeO	6.50 .090	5.88 .082
MnO.....	.11	.15
MgO	20.86 .521	30.00 .750
CaO	13.23 .236	5.60 .100
Na_2O....	.22 .003	.47 .007
K_2O	.10 .001	.55 .005
H_2O.....	.57	5.32
Others ...	.50	1.64
Total ..	100.37	100.49

RARE ROCK TYPES OF GRANITIC TEXTURE

	1 Rockallite	2 Basic nepheline-syenite	3 Urtite	4 Ijolite	5 Missourite	6 Dunite
SiO_2	73.60 1.218	41.37 .684	45.28 .749	44.71 .740	40.06 .768	29.81 .493
TiO_2	....	....	....	1.41	.73	2.20
Al_2O_3 ...	4.70 .046	16.25 .159	27.37 .267	17.46 .170	10.01 .098	2.01 .019
Fe_2O_3 ...	13.10 .082	16.93 .106	3.53 .022	5.15 .032	3.17 .019	5.16 .032
FeO	....	....	.49 .007	3.71 .052	5.61 .078	4.35 .060
MnO	.93	....	.19	.20	....	.23
MgO	.11 .003	4.57 .113	.33 .009	2.67 .060	14.74 .364	32.41 .810
CaO	.37 .007	12.35 .221	1.22 .022	11.50 .205	10.55 .189	7.69 .137
Na_2O ...	6.96 .112	4.18 .067	17.29 .279	8.73 .141	1.31 .021	.11 .001
K_2O	....	3.98 .042	3.51 .037	1.82 .019	5.14 .054	.20 .002
H_2O	....	.45	.40	.67	1.44	8.92
Others ...	.06	....	....	.85	.81	7.77
Total ..	99.83	100.08	99.61	98.88	99.57	100.86

COMPOSITES OF ROCK TYPES OF RHYOLITIC TEXTURE

	[illegible] (8)	[illegible] (6)	Pantellerite (4)	Trachyte (6)	Domite (2)	Volcanite (1)	Dacite (6)	Andesite (7)	Toscanite (10)	Vulsinite (10)	Ciminite[1] (11)	Banakite (4)	Shoshonite (5)	Absarokite (5)
[illegible]	74.12 [illegible]	74.50 [illegible]	68.88 1.140	63.97 1.069	67.54 1.118	66.99 1.109	68.25 1.129	62.16 1.029	67.74 1.121	58.97 .976	56.18 .930	52.06 .868	53.19 .886	49.21 .820
[illegible]	[illegible]	......	......	.36	......	......	......	.23	......	......	.15	.76	.74	.92
[illegible]	[illegible]	13.67 .134	8.01 .078	17.62 .172	16.96 .166	17.56 .172	16.35 .160	16.45 .161	14.77 .144	17.84 .174	16.24 .159	17.66 .173	17.81 .174	12.52 .122
[illegible]	[illegible]	[illegible]	6.72 .042	2.01 .012	2.97 .018	1.41 .008	1.78 .011	3.27 .020	.60 .004	1.67 .010	2.31 .014	4.66 .029	4.25 .026	4.34 .027
[illegible]	[illegible]	[illegible]	3.37 .047	1.60 .022	.37 .005	3.39 .047	1.19 .016	2.71 .038	3.15 .044	4.67 .065	6.17 .086	2.20 .030	3.07 .043	4.15 .057
[illegible]	[illegible]	[illegible]	......	......	.13	......	.01	.02	......	.03	.23	.13	.11	.13
MgO	[illegible]	[illegible] .066	.62 .015	.92 .023	2.08 .051	.93 .023	1.21 .030	2.20 .055	1.06 .024	1.67 .041	3.95 .098	3.33 .083	3.64 .091	10.36 .259
CaO	1.11 .020	1.17 .021	1.46 .026	2.32 .041	2.02 .036	4.25 .076	3.03 .054	4.13 .074	2.99 .053	5.02 .090	6.25 .112	5.11 .091	6.25 .111	8.14 .140
[illegible]	2.67 .037	3.90 .048	6.78 .094	4.62 .064	4.80 .077	3 35 .054	4.31 .060	4.07 .056	3.25 .052	2.76 .045	2.44 .039	4.09 .057	3.43 .047	2.01 .028
[illegible]	[illegible]	2.98 .031	3.35 .035	5.59 .059	3.57 .038	.34 .003	2.48 .026	3.45 .037	4.16 .044	5.86 .060	4.44 .047	5.03 .053	3.88 .041	3.74 .040
[illegible]	[illegible]	.39	.44	1.14	.39	1.53	1.09	1.15	1.92	1.34	1.59	3.74	2.73	3.96
[illegible]	[illegible]	......	......	.03	.60	......	.06	.15	.42	.24	.37	.84	.71	.71
Total	[illegible]	99.78	99.63	100.18	100.13	99.75	99.76	99.99	100.06	100.07	100.32	99.64	99.81	100.53

[1] The analyses on which this composite is based are too high in alumina and too low in magnesia. Cf. Washington, Am. Jour. Sci. (4) IX, p. 44, 1900.

DENTITION OF SOME DEVONIAN FISHES

During the last few years our knowledge of the multiplicity and relationships of the Middle and Upper Devonian fish-faunas in this country has been enlarged by the discovery of much new material. Exceptionally interesting finds have been made in the Marcellus, Hamilton, and Naples shales of New York, the Chemung-Catskill of Pennsylvania and its presumable equivalent in Johnson county, Iowa, in the Corniferous of Ohio, and in the Hamilton limestone of Wisconsin and adjoining states. From the last-named horizon notable collections have been brought together and rendered accessible for study by Messrs. E. E. Teller and C. E. Monroe and the late T. A. Greene of Milwaukee, and Professors Calvin and Udden of the Iowa State Geological Survey. These have been freely drawn upon in the preparation of the following notes.

GENUS *DINICHTHYS*, NEWBERRY

So intimately related are the two best-known Arthrodires, *Coccosteus* and *Dinichthys*, that the only crucial test of generic distinctness is afforded by the dentition. Likewise, for the discrimination of species, dental characters are all-important. Among the body-plates the chief distinctive characters are furnished by the dorso-median and clavicular.

1. *D. pustulosus* E. (Fig. 1). — Although remains of this Hamilton Dinichthyid are tolerably abundant, nothing was known of its dentition until recently, when one large premaxillary, nearly equaling that of *D. terrelli* in size, and two maxillary or shear-teeth were found by Mr. Teller in the hydraulic cement quarries of Milwaukee. Last fall a fragmentary mandible showing rudimentary denticles along the posterior slope of the cutting edge was obtained from the Hamilton of New Buffalo, Iowa, by Professor Udden, and still more recently Mr. Monroe

was fortunate enough to secure at the typical Milwaukee locality the specimen shown in Fig. 1.

The inner face of this specimen is attached to a block of limestone, a part of the anterior extremity is broken away, and a considerable portion of the posterior end is missing. The total length may be estimated at about 24^{cm}, the proportions being about the same as in *D. curtus*, and about three quarters the size of an adult individual of *D. intermedius*. The posterior

FIG. 1. *Dinichthys pustulosus* E. Hamilton; Milwaukee, Wisconsin. Left mandible. × ½.

end is more slender than in either of these species, and the cutting edge also differs in having no prominence back of the tooth-like beak. The cutting edge of *D. intermedius* has one such prominence, and that of *D. curtus* two. In *D. curtus* "the posterior end of the cutting edge is set with two or three unequal denticles in place of the series of even, lancet-like points in the same position on the mandible of *D. intermedius*."[1] But in the present form these denticles are reduced to mere swellings, of which five may be counted along the posterior slope of the cutting edge. Professor Udden's specimens, altho smaller, shows the bosses more prominently; they are, in fact, rudimentary denticles, and represent the initial stage of those structures which are such a conspicuous feature in *D. herzeri* of the Ohio Shale.

[1] NEWBERRY, J. S., Pal. Fishes N. A. (Mon. U. S. Geol. Surv., Vol. XVI, p. 156), 1889.

The cutting edge of the mandible is beveled to a sharp edge, and shows the usual indications of wear. It belonged to an average or slightly undersized individual, judging from the proportions of a dozen crania that have been found at Milwaukee. The largest of these, it should be noted, is only one fifth smaller than an averaged-sized head of *D. terrelli*. The premaxillaries and shear-teeth do not call for any special comment, except that the latter are without denticles on the posterior margin.

2. *D. halmodeus* (Clarke).—The presence in the type specimen of functional premaxillary teeth, and of a carinal process on the under side of the dorso-median, are sufficient reasons for transferring this species from *Coccosteus* to *Dinichthys*. The mandibles, which measure about 6.5^{cm} in length, have in place of a cutting edge a series of seven or more backwardly directed denticles. The anterior beak is missing in both mandibles, and the premaxillaries are also damaged. The latter are relatively very powerful, and provided with an elongated base for attachment to the visceral surface of the cranium. The plates designated as *x*, *mx*, *pmx*, and *pto*, in Dr. Clarke's diagram[1] are all parts of a single element, the suborbital. Examination shows that the cranial osteology and structure of the dorso-median are normal in every way.

3. *D. herzeri* Newb.—This species is commonly supposed to be limited to the Huron Shale, but it probably had a continuous range from base to summit of the Ohio Shale. Its occurrence in the Cleveland Shale may be strongly suspected, if indeed it is not proved by two specimens described by E. W. Claypole. The first is the fragmentary mandible known as *D. kepleri* Cl.,[2] and the second is the series of massive plates (plastron and clavicular) preserved in the Ohio State Museum, and figured in part in Vol. VII of the *Ohio Geological Survey Reports* (Pl. XXXVIII–XL). The clavicular and postero-ventro-median each have a length of about 50^{cm}, and the postero-ventro-laterals are over 76^{cm}

[1] Thirteenth Ann. Rep. State Geol. N. Y., Vol. I, 1893, p. 162.

[2] Amer. Geol., Vol. XIX, 1897, p. 322, Pl. XX.

long, indicating a creature about two fifths larger than the average of *D. terrelli*. Believing these proportions too large for any known species of *Dinichthys*, Claypole[1] referred the remains to *Titanichthys;* and later the name of *D. ingens* was suggested for them by Wright.[2] We propose to cancel both this title and that of *D. kepleri* in favor of the type species of *Dinichthys*. Other plates of huge size belonging in all probability to the same species are preserved in the museum of Kentucky State University at Lexington.

4. *D. clarki* (Claypole).—A large species of *Dinichthys* allied to the preceding, so far as may be judged from the dentition, was made the type of a new genus by Claypole,[3] and named by him *Gorgonichthys clarki*. No characters are shown, however, which warrant a separation of this form from *Dinichthys;* on the contrary, the mandible displays an interesting stage of modification between denticulated forms like *D. herzeri*, *D. halmodeus*, etc., on the one hand, and those with a sharp cutting edge like *D. terrelli* on the other.

The type of the so-called "*Gorgonichthys*" and the large premaxillary described by Claypole[4] as *Dinichthys clarki* have, of course, nothing in common. The relations of the latter are not accurately determinable. If excluded from *Dinichthys*, a new generic name will be required; if retained, a new specific name is necessary.

GENUS *CLADODUS*, AGASSIZ

This typically Carboniferous genus occurs sparingly in the Neodevonian, but no species have been reported from Mesodevonian horizons. That it was present, however, in both the Corniferous and Hamilton periods is proved by at least two specimens which have come under the writer's observation. One of these is a large tooth from the Corniferous limestone of Columbus, Ohio, now preserved in the American Museum of

[1] Rep. Ohio Geol. Survey, Vol. VII, 1893, p. 611.

[2] Bull. Mus. Comp. Zoöl., Vol. XXXI, 1897, p. 24.

[3] Amer. Geol., Vol. X, 1892, p. 1.

[4] *Ibid.*, Vol. XII, 1893, p. 278.

Natural History in New York (Cat. No. 4257). Although very similar to *C. striatus* Ag., it probably belongs to a distinct species.

C. monroei, sp. nov. (Fig. 3).—The type of this species is a small, imperfectly preserved tooth found by Mr. C. E. Monroe in the Hamilton of Milwaukee. The drawing reproduced herewith is made up from both halves of the counterpart containing the specimen. Traces of striae appear in places, but are nearly

2

3

FIG. 2. *Cladodus monroei* sp. nov. Hamilton limestone; Milwaukee, Wisconsin. × $\frac{1}{1}$.

FIG. 3. Supposed cone-scale from Kinderhook fish-bed at Burlington, Iowa. × $\frac{1}{1}$.

obliterated by decay of the enamel and dentine, and portions of the crown and base are broken away. The crown is robust, being very thick at the base, and the external denticles are proportionately stout. Three cusps of small size intervene on each side between the principal cone and external denticles. The total height may be estimated at about 1.3^{cm}, and the width of base at 2.5^{cm}.

Other Corniferous forms occurring in the same horizon at Milwaukee are teeth and plates of *Onychodus*, spines of *Machaeracanthus*, and Chimaeroid remains. *Macropetalichthys* and *Asterosteus*, however (which on account of their cranial osteology and lack of dentition we must now exclude from *Arthrodira* and place with the Ostracoderms as degenerate Elasmobranch offshoots), are conspicuously absent.

GENUS *DIPTERUS*, SEDGWICK AND MURCHISON

There are two distributional centers for this genus in America, between which there was apparently no communication. In the eastern province, which includes the Chemung-Catskill of New York and Pennsylvania, it is associated with forms common to the Upper Devonian of Canada and Europe. In the western province (Iowa and Illinois to Manitoba) it ranges from the base of the Hamilton to near the top of the Devonian and is accompanied by *Ptyctodus* and a number of Dipnoan forms peculiar to this region.[1] Here are found no traces of Crossopterygians or Ostracoderms; in fact the western Neodevonian fish-fuana is entirely distinct from the eastern, and represents a different migratory movement.

The Chemung proper contains but two well-recognized species of Dipterus, *D. flabelliformis* and *D. nelsoni*, the latter including Newberry's so-called *D. levis* (founded on worn specimens), and possibly *D. quadratus* and *D. minutus*. From the Catskill of Pennsylvania four species are known: *D. sherwoodi*, *D. fleischeri*, *D. angustus* and *D. contraversus* (= *D. radiatus* N.). Several of these species are founded on imperfect material, and the original descriptions require emendation. To this list may now be added four new species from the Middle and Upper Devonian of Iowa, the types of which are preserved in the Museum of Comparative Zoölogy at Cambridge, Massachusetts.

1. *D. uddeni*, sp. nov. (Fig. 5).—This species is established on a unique mandibular dental plate from the base of the Cedar Valley limestone (Middle Devonian) near New Buffalo, Iowa. It has a total length of 36^{mm}, is moderately convex, and remarkable for the paucity of its denticulated ridges. These are only four in number, and radiate in gently curved lines from the posterior angle, which is worn smooth by use. The anterior row of denticles and inner moiety of the remaining rows are also considerably worn; but in the outer moiety of these rows the denticles are acutely conical, of large size and well separated.

[1] Ann. Rep. Iowa Geol. Surv., Vol. VII (1896), Pl. IV; *ibid*, Vol. IX (1898), p. 302; JOUR. GEOL., Vol. VII (1899), p. 77.

There is a progressive diminution in size of all denticles proceeding posteriorly. The coronal surface is finely punctate.

This beautiful dental plate is the oldest of all *Dipterus* remains that have been found in this country. It was discovered by Professor J. A. Udden of Augustana College, Rock Island, in

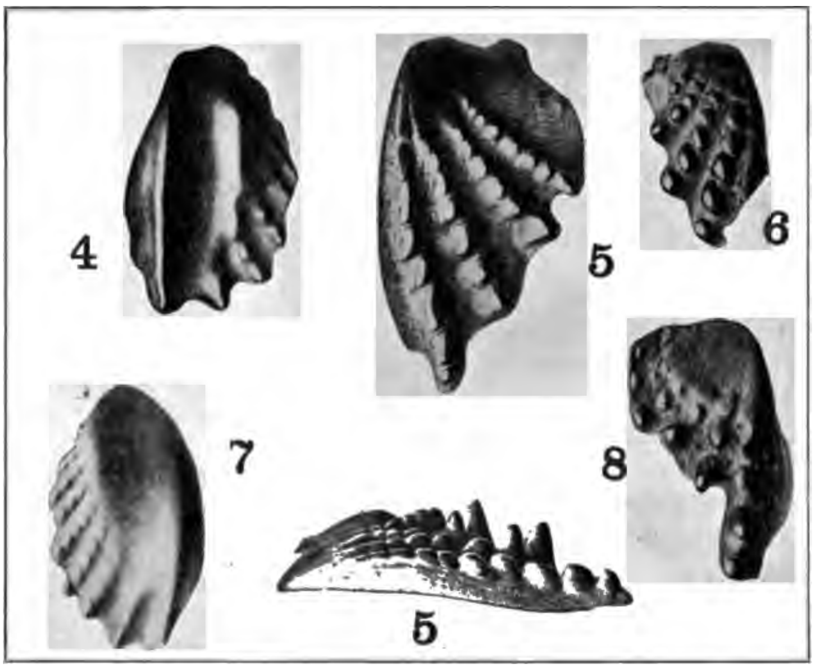

FIG. 4. *Dipterus costatus* sp. nov. Upper Devonian; Johnson county, Iowa.

FIGS. 5, 5[1]. *Dipterus uddeni* sp. nov. Cedar Valley limestone; New Buffalo, Iowa.

FIGS. 6, 8. *Dipterus mordax* sp. nov. Upper Devonian; Johnson county, Iowa.

FIG. 7. *Dipterus calvini* sp. nov. Cedar Valley limestone; Fairport, Iowa.

whose honor the specific title is dedicated. A note of its geological occurrence was published in the August number of this JOURNAL (p. 494) for last year.

2. *D. calvini*, sp. nov. (Fig. 7).—Like the last, this species is founded on a unique dental plate (right mandibular) from the Cedar Valley limestone of Iowa. It comes from a higher level,

however, having been found by Professor Udden in the so-called "Euomphalus bed" at Fairport, Muscatine county, which lies about eight feet below the summit of the Cedar Valley limestone, or Hamilton of Worthen and others.

The plate is elliptical in outline, and moderately convex in an antero-posterior direction. Eight tuberculated ridges extend from the outer margin to about the center of the plate, the two anterior ones being the largest and elevated into a slight fold. Coronal surface considerably worn, and external margin partially broken. Tubercles conical and well separated, except those of the two anterior ridges, which are coalesced and worn on their summits. Total length of plate 3^{cm}. Named in honor of Professor Samuel Calvin, State Geologist of Iowa.

3. *D. costatus*, sp. nov. (Fig. 4).—This plate agrees in size and general outline with *D. calvini*, but it has fewer and more widely separated coronal ridges which disappear before reaching the center of the plate. The distinguishing feature of this species consists in the elevated sharp ridge extending along the entire length of the inner margin, and separated from the remaining tuberculated ridges by a broad longitudinal furrow. This ridge appears to be of compound origin, or made up of three coalesced costae, of which the third counting from the inner margin is the largest. The two innermost costae are so faint as to be almost imperceptible on the steep face of the main ridge. The summit of the latter is sharp, and shows no evidence of being made up of tubercles. The tubercles of the five marginal ridges are also worn nearly smooth and more or less coalesced. But for the convexity (in a longitudinal direction) of the coronal surface this might be taken for an upper dental plate. Several examples of this form have been obtained from the State Quarry fish-bed near North Liberty, in Johnson county, Iowa.

4. *D. mordax*, sp. nov. (Figs. 6, 8).—Dental plate attaining a length of over 3^{cm}, coronal surface gently convex, with six rows of very large, well separated conical or rounded tubercles which extend from the outer margin for a variable distance

toward the posterior angle; the two posterior rows often rudimentary. Some of the tubercles, when worn by use, become elongated in the direction of the rows to which they belong, and others in an oblique direction. This species is readily distinguished from all others previously described by the relative coarseness of its tuberculation. It is represented by a number of examples from the State Quarry beds of Johnson county, Iowa.

NOTICE OF PROBLEMATICAL ORGANISMS

Some thirty years ago Mr. Orestes St. John, when assistant in the Museum of Comparative Zoölogy, collected a number of Selachian teeth and spines and some large Dinichthyid plates from a "fish-bed" near Burlington, Iowa, supposed to be near the dividing line between Upper Devonian and typical Kinderhook. Small spines of *Stethacanthus*, *Erismacanthus*, and *Homacanthus* are rather abundant at this locality, also dermal tubercles of sharks. From the upper part of the formation Mr. St. John obtained the carapace of a Schizopod crustacean, and also some vegetable remains, such as branches of a Lepidodendron and woody fibers. In addition he found a number of peculiar fossils of which the one shown in Fig. 2 is a fair example, and within the past year other specimens of the same sort have been collected by Professor Udden in the Kinderhook near Burlington.

An examination of the latter forms by Professor Arthur Hollick of Columbia College leads him to the opinion that they are cone-scales of some conifer probably allied to *Araucaria*. A figure is given herewith for the benefit of those interested in the study of Mississippian faunas.

EXPLANATION OF FIGURES

FIG. 1. *Dinichthys pustulosus* E. Hamilton limestone; Milwaukee, Wisconsin. Left ramus of mandible. $\times \frac{2}{5}$.

FIG. 2. *Cladodus monroei* sp. nov. Hamilton limestone; Milwaukee, Wisconsin. $\times \frac{2}{1}$.

FIG. 3. Supposed cone-scale from Kinderhook fish-bed at Burlington, Iowa. $\times \frac{2}{1}$.

FIG. 4. ***Dipterus costatus*** sp. nov. Upper Devonian; Johnson county, Iowa. Left lower dental plate.

FIGS. 5, 5[1]. ***Dipterus uddeni*** sp. nov. Cedar Valley limestone; New Buffalo, Iowa. Left lower dental plate, oval surface and profile.

FIG. 6, 8. ***Dipterus mordax*** sp. nov. Upper Devonian; Johnson county, Iowa. Somewhat worn examples of right lower dental plates.

FIG. 7. ***Dipterus calvini*** sp. nov. Cedar Valley limestone; Fairport, Iowa. Right lower dental plate.

[Figs. 4–8 reduced slightly less than natural size.]

C. R. EASTMAN.

ANCIENT ALPINE GLACIERS OF THE SIERRA COSTA MOUNTAINS IN CALIFORNIA

INTRODUCTION

NORTHWESTERN California is a vast complex of mountains, forming the Klamath system, whose geological features are similar to those of the Sierra Nevada range. Centrally situated within it is a series of high granitic and syenitic peaks, constituting the range of the Sierra Costa Mountains. Beginning in Castle Crag, about fifteen miles southwest of the lofty volcanic peak of Mt. Shasta, they trend thence southwestward about fifty miles, with an average width of between fifteen and twenty miles. Within this territory of eight or nine hundred square miles there are a score or more of bare, ragged peaks rising to altitudes of 7200 to 9345 feet above the sea. Between them are deep, narrow valleys whose floors have altitudes between 2500 and 6500 feet, averaging about 4000 feet. Some of the more elevated of these present distinct evidences of past glaciation. The glaciers were very localized in development, never coalescing to form a general glaciation of any part of the territory, and hence the glacial phenomena displayed in these mountain valleys are characteristically different from those of the drift-covered regions of the Mississippi basin.

GENERAL DESCRIPTION OF THE GLACIAL PHENOMENA

There is a radical difference in topography between the glaciated and non-glaciated valleys. The latter are V-shaped gulches with steep straight slopes and a width at the bottom often but little greater than that of the stream flowing within them. In places they are very rocky, with jagged ledges projecting from their sides. All the stony material found on their slopes is of the rock species underlying the soil on each particular slope. The same valley, traced up to where it once possessed a glacier, will rather abruptly change its form to a broad and

open U-shaped trough, with smooth and curved slopes, and a gently rounded floor. This change has been effected by a grinding away of the talus material and solid rock along the middle levels of the slopes and a filling of the extremely narrow lower portion of the gulch. The ravines have been destroyed, partly by filling and partly by the grinding away of the intervening ledges. Often this smoothing of the contours has extended up to a certain level, above which the mountain sides are deeply scored with ravines, and jagged with outcropping ledges.

Most of the valleys present but a moderate amount of ground-moraine, altho the lateral moraines are well developed. The glaciated slopes are abundantly supplied with bowlders of all the rock species occurring from thence to the head of the valley. They are embedded in a loose agglomeration of subangular gravel, sand and a little clay, forming a deposit quite unlike the till of the Mississippi basin, altho somewhat more nearly resembling the very stony moraines of New England. These lateral moraines are smooth in outline, rarely displaying a hummocky topography, and only in a few cases standing out distinct from the mountain ridges. In the unglaciated gulches, especially where the country rock is serpentine, extensive land slips are resting on the lower slopes, and they present a hummocky topography almost identical with that so characteristic of glacial moraines in the Mississippi basin, even to the extent of possessing kettle-holes containing lakelets. These must not be confounded with the lateral moraines.

Lines of erratics perched high on the mountain sides sometimes indicate the maximum altitude of the glacial action. From the smooth curved slopes of the lateral moraines, low narrow ridges of very stony material trend obliquely toward the center of the valley, those on opposite sides forming a loop, pointed downward. Sometimes they coalesce and are then cut by a small canyon-shaped valley thru which the stream finds an outlet from the enclosed basin above. These are the only representatives of true terminal moraines (being formed at successive

stages of readvance during the general recession of the glacier), but are quite insignificant as compared with the lateral moraines.

Near the heads of the glaciated valleys the rock surface is often bare over thousands of square feet, and is then seen to be smoothed and rounded by the grinding action of the ice. Some distinct grooves appear, but are not common. Of more frequent occurrence are fine lines or striæ, altho where long exposed these have been destroyed by weathering.

By far the most characteristic of the glacial phenomena of the Sierra Costa Mountains are the high meadows and lakelets. The former are smooth expanses of the valley floor a mile or more in length by half as great width, occurring near the heads of the valleys. They are inclined to be damp and boggy, and are grassed, instead of timbered and brushy, as other portions of the mountain region. They are underlaid with a fine gravelly silty ground moraine, and over their surfaces are frequently scattered large erratics of an englacial and superglacial mode of transportation. The lakelets are rounded bodies of clear cold water, varying from a fraction of an acre to twenty or more acres in extent, sometimes occupying rock-bound basins of glacial origin, but generally held in behind moraines. Around the border may be a tiny beach of white sand, or a narrow strip of flat, grassy land composed of black peaty soil. Some of these tiny mountain tarns are perched high up on the mountain sides in small coves or niches abraded from the solid rock by the downward pressure of the ice under the *névés*. A few of these coves are hundreds of feet in depth, have steep, often precipitous, rock-walls, and are nearly closed in by the surrounding ridges so that they closely resemble the *cirques* of the Alps.

An especially favorable situation for the glacial lakelets is at the foot of high rock precipices which usually occur on the southern or western sides of the valleys. The glaciers invariably hugged the shady side of the valleys and there accomplished their most active grinding work. It was on the northern side of the frowning peaks that the ice laid longest, and when its final melting

was accomplished, depressions were left at the foot of the precipices which had been produced by the removal of the talus material and some of the solid rock. In several cases one may stand on a high peak and throw a stone so that it will drop into the clear water of a lakelet, 1000 feet below. These high precipices are another characteristic of the glaciated valleys, for they never occur elsewhere in these California mountains.

The glaciers headed in valleys whose altitude is now between 6500 and 7500 feet above the sea, and descended to 5000 or 5500 feet (with two notable exceptions). Thus the declivity of the glaciated valleys is great; but the descent is effected by a series of terraces or steps, gentle slopes alternating with steep, almost precipitous, sections where the valley floor is rapidly let down 100, 200 or even as much as 500 feet vertically. These "steps" are only in small part due to moraines, being composed mainly of solid rock. Over them the glaciers cascaded, forming extensive crevasses, then coalescing into a solid mass and moving along smoothly a mile or more to the next cascade. Toward the close of the ice period, when the main glaciers had shrunk to insignificant remnants, tiny glaciers continued to issue from under the local *névés* in the coves high up on the mountain sides, and cascaded over precipices as much as 500 feet in height.

I have mentioned a sufficient number of the features of these valleys to place it beyond doubt that they have suffered glaciation in some past period, and to demonstrate that the glacial action was essentially identical in character with that at present obtaining in the high Alpine valleys of Switzerland.

CHARACTERISTIC FEATURES OF INDIVIDUAL GLACIERS

The Castle Creek glacier.—At its maximum extension, this glacier had a length of about two miles, a width of one quarter to one half mile and a depth of 500 to 800 feet. It was situated at the northern foot of Tamarack peak, near the junction between Trinity, Shasta and Siskiyou counties. The present altitude is about 6500 feet. Within the limits of its site are six pretty lakelets, one lying at the foot of a 1000-foot precipice. The glacier

flowed in an easterly direction and hugged the southern side of the valley, there leaving the rock bare of talus or morainic material. In receding, it melted away from the warm northern side of the valley, and left several successive lateral moraines on the valley floor, running lengthwise of it. The last of the series is about in the center. A trough shaped depression occupying the southern half of the valley indicates the final track of the dying glacier. In it lie some of the lakelets. A tributary glacier entered the main trunk at nearly a right angle, and cascaded over a rock-ledge now 500 feet above the main valley floor. The ledge is smoothed and striated. Above it a lakelet is held behind a moraine composed of clay, sand, gravel and bowlders, some of which are beautifully striated. The interesting feature of this glacier was its evident sensibility to the sun, causing it to melt away from the sunny side of the valley long before it disappeared from within the shadow of Tamarack peak.

The Salmon River glacier.—This was seven miles in length, one half to one mile in width and 1000 to 1500 feet in depth. Its course was a little east of north. It headed at about 6500 feet of altitude (present), and descended but little below 5500 feet. On the west of its upper half was the high granite peak of Mt. Courtney, whose slope is now bare of loose rocks and soil from summit to base and is worn smooth and rounded by glacial abrasion. From the precipitous pinnacles of the sawlike crest, huge bowlders of granite crashed down upon the ice, and now lie scattered upon the floor of the valley and even over the opposite slope. Several are as large as an average miner's cabin. Beyond the granite of Mt. Courtney, where the rocks are mainly hornblende and mica schists, the upper limit of the glacier is clearly defined high on the mountain sides by a sharp line below which granite bowlders are numerous and above which there are none; also, by shoulders or small precipices on the inter-ravine spurs of the mountain on the east, showing to what height the glacial abrasion extended.

Many prospectors and semi-scientific observers have noted the fact that the upper four or five miles of the original main

Coffee Creek has been beheaded and added to the South Fork of Salmon River, but not many have clearly discerned that this was due to glacial action. In ascending the Upper Coffee Creek valley, after the great bend is passed, the floor widens to quite a plain, there being here a heavy filling of waterlaid gravel and sand, the extra-glacial deposit of the glacier above; on this, at the mouth of each tributary gulch, there is a beautiful alluvial fan. About one and one half miles below the head of the creek, a slight ridge crossing the valley and carrying granite erratics marks the extreme limit of the glacier. From here to the summit stretches the "Big Flat," a smooth plain of fine gravel and sand (with scattered granite erratics) about one and one half miles in length and one half mile in width. At its upper end (which is the summit of the Sierra Costa Mountains, the water-parting between the main Klamath and the Trinity River systems, and the Trinity-Siskiyou county line) there is the slightest tendency to a morainic character. This "Big Flat" has an altitude of 5500 feet while the mountains on either hand rise to 7000 and 7500 feet. Here the glacier made a filling several hundred feet in thickness, thus obstructing the valley. At the same time it wore the rock wall of the valley on the west (which had already been nearly cut thru by the head water erosion of the original South Fork of Salmon River) so thin that a glacial stream crossed the ridge in a col and soon cut down a gorge. Hence it is that the South Fork of Salmon River rises in the head of the original Coffee Creek valley, follows it for four or five miles until within a few hundred yards of the present head of Coffee Creek, then turns to the west at a right angle, and passing out of the broad valley thru a narrow gorge where it abounds in rapids and falls, it makes its way thru unglaciated gulches to the Klamath. This is one of the finest examples of the beheading of a stream by glacial action that I know of.

As indicated by the granite erratics, the surface of this Salmon River glacier descended 1000 feet (and the glacier thinned to that amount) in the last one and one half miles of its course.

[illegible] the South Fork of the Salmon
[illegible] gorge or tiny canyon in
[illegible] This is twenty to thirty
[illegible] no wider than the
[illegible] in rapids and low

[illegible] the next main series
[illegible] River glacier. There
[illegible] two branches each
[illegible] one quarter to one half
[illegible] feet. They
[illegible] and the main
[illegible] Near its end it
[illegible] the original
[illegible] by its very
[illegible] obstructs the
[illegible] which was not
[illegible] occupied valleys
[illegible] too directly

[illegible] dissevering
[illegible] Union Valleys,
[illegible] and formed a
[illegible] junction. The
[illegible] cut into the
[illegible] the moraine.
[illegible] This shows
[illegible] as early as the
[illegible] glacier. The
[illegible] this steep
[illegible] these

[illegible] are well

[illegible] this
[illegible] a low

altitude, its heavy ground moraine, and its beautiful terminal moraine.

At its maximum extension, this glacier had a length of not less than fifteen miles, a width of one half to one mile, and a depth of 1000 to 1500 feet. It was the largest single mass of ice, so far as I know, of the Sierra Costa Mountains. It headed among the peaks in the highest portion of this range, at an altitude now about 6500 feet, trended in an easterly direction, forming the broad flat of the Mumford meadows (altitude 5500 feet), then ran southeasterly, descending rapidly to a level now little more than 3500 feet above the sea, where at ten miles from its head, it suddenly issued from the high mountains, and turning to the northeast, it deployed upon and across a broad basin valley of Miocene age and later, and terminated very close to the site of the Redding and Trinity Centre road at an elevation now no greater than 2500 feet above the sea. Here are, so far as I am aware, the least elevated direct glacial deposits west of the Sacramento River, if not in the whole state of California.

Among the prospectors of northern California, the "cemented gravel of Swift Creek" is a term to conjure with. It is essentially non-gold-bearing, and so far as the ability of the average miner to sink a shaft through it is concerned, it is bottomless. It is an unstratified agglomeration of bowlders, cobbles, pebbles, sand, silt, and clay, which occupies the valley from head to mouth, forms the flats or meadows, and is trenched by a narrow canyon carved by Swift Creek in postglacial time. Where the stream, in undermining a bank, has made a recent excavation, the deposit has an extremely fresh appearance and a delicate light bluish tint. Many of the included bowlders are rounded and polished, and not a few are beautifully striated. It is as typical a till as any to be found on this continent. Being largely the result of glacial abrasion on the rock floor and walls of the valley (serpentine mainly), it is slightly cemented by the large constituent of unoxidized magnesian and calcareous salts. Most of the included rock fragments are serpentine of the black

amorphose variety, and the light oil-green schistose variety, and the blue tinting was derived from the grinding of this formation. It cannot be worked for its included gold as a placer deposit, because there has been no concentration of the precious metal by water action as in ordinary stream alluvium.

This fine deposit of subglacial till or ground moraine attains its fullest development about midway of the course of the glacier where it must have a depth in places of not less than several hundred feet. At an altitude of about 5000 feet, the most prominent glacial features cease. Beyond this the valley contracts and descends rapidly over a series of high steps, which are strewn with a profusion of bowlders, some of which are striated. Everything here is confusion — there may be indistinct terminal moraines, lateral ridges, *roches moutones*, and some ground moraine, but the best expert cannot get much regularity out of the piles of bowlders heterogeneously distributed along the slopes of the bounding mountains and on the irregular valley floor. Here the creek descends rapidly in one long series of rapids and cascades, along its bowlder strewn bed, and in one place has cut a beautiful gorge thru the solid serpentine rock. It is several hundred feet in length and thirty to fifty feet in depth, and no wider than the stream. With its perpendicular and even overhanging walls, it is a veritable cañyon. It abounds in *remolinos* (pot-holes) whose mode of formation can plainly be seen, from the clearness of the water.

When the Swift Creek glacier issued from the deep valley in the high Sierra Costa Mountains and deployed across the Miocene basin, it did not spread out as an alluvial delta, but it maintained its narrowness to the end, five miles distant. Around this extra-montane portion it formed a beautiful moraine. The constitution of this is essentially similar to that of the cemented gravel farther up the creek, except that it contains less clay, is looser and coarser in texture, and has some large erratics on its surface. Where trenched by tributary creeks and its interior freshly exposed, polished and striated pebbles and bowlders are not difficult to find. Two parallel ridges of about equal height,

and even crests, trend from the sides of the mouth of the upper valley northeastwardly across the Miocene basin, gradually descending toward Trinity River. Between them is a flat-bottomed, steep sided depressed area, 300 to 500 feet in depth and one half mile in width, evidently representing the cross-section of the glacial tongue. From the crests of the ridges more gentle slopes of very bowldery land extend outward and gradually merge with the erosion surface. These ridges are the extra-montane extensions of the lateral moraine, but also contain ground moraine and may be considered a terminal moraine. Near the Trinity River they flatten down, become hummocky and indistinct, but appear to curve around the end of the site of the ancient glacier and connect, except for the postglacial canyon which the stream has cut thru the moraine. Beyond this is a fine example of a fan-shaped extra-glacial delta, which occupies several square miles in the valley of the Trinity River, and its outer edge descends almost to the level of that stream itself.

This glacial tongue reached the northern end of the low Minerva range of mountains, and built its moraine across the mouths of several of the gulches. These have been filled nearly to the level of the moraine summit by fine silts, and form extensive grassy flats composed of deep black soil free from pebbles. Along the moraine the flats have some large angular erratics on their surface; these have slidden from the surface of the glacier.

In the bottom of the depressed area within the moraine Swift Creek has eroded a canyon 75 to 150 feet deep and 300 to 500 feet wide, widening and shallowing toward the mouth. This seems large, but represents glacial as well postglacial stream erosion.

On the whole, the glacial features of the Swift Creek valley are extremely interesting and instructive, and, from its accessibility, should become classical among students of California Quaternary geology.

The East Fork glacier.—This occupied a high valley, steeply descending on the east face of Granite Peak, a few miles northwest of Minersville. Near its head a precipitous mountain side

shows the smoothing and rounding action of the glacier up to a certain height, above which the bare rock is extremely rough and jagged. Some glacial grooves are seen and a little striation. In another place there is a well-defined line of perched erratics.

This glacier also issued from the high mountains, and it cut directly thru the old Miocene river channel, carrying its huge granite bowlders nearly or quite to the Minersville-Trinity Centre road, terminating at a point probably now no greater than 3000 feet of altitude. It is a well-known fact that all the gulches which are cut into this old Miocene channel deposit have been rich in placer gold, except the valley of the East Fork, which cuts directly thru it, and yet never paid to work. The apparent anomaly is explained when it is understood that the East Fork glacier ground all of the gold-bearing alluvium out of the valley and left in its place its own only slightly auriferous deposit—the glaciated valleys are never worked as placers.

Quite a number of other valleys in the Sierra Costa Mountains were once occupied by glaciers. The presence of a number of lakes (as mapped) in the deep canyons south and east of Mt. Thompson of the granite Cariboo range seem to indicate that a cluster of them occupied that region. Probably a score or more existed in Trinity county alone; but the examples given in this paper are typical of them all, and will suffice for the purposes of the present study.

THE AGE OF THE GLACIERS

At one time I thought I had detected evidences of two glacial epochs in the Sierra Costa Mountains, one very recent and another much older, but I have had to revise this opinion. The deposits near the lower end of the glaciated valleys are of slightly more aged appearance than those near the heads, but the contrast is not great. They are essentially a unit, so far as age is concerned.

The weathering of the once striated, polished, and perfectly smoothed rock surface, the erosion of small canyons in the rock-floors of several of the glaciated valleys near their heads, and

the peaty accumulations about the borders and on the bottoms of the lakelets show that the glaciation has not just terminated—the ice has been completely gone for at least several thousand years. Yet the many lakelets held behind frail barriers of till, the cascades and rapids, and the generally uneroded condition of the drift tell, in unmistakable terms, of the comparative recency, geologically speaking, of the glaciation. Subaerial erosion, aside from one main stream channel in each valley, has been practically nothing. Even the excavation of the single central canyon was largely accomplished while the ice yet lingered in the heads of the valleys, and by its rapid melting greatly increased the streams. With the steep declivities and the heavy annual precipitation, it is remarkable how little erosion has been accomplished in northwestern California since the glacial epoch. Certain cemented river gravels in the valleys of the East Fork of Trinity River, the main Trinity River, and lower Coffee Creek, which represent the outflow from the glacier, rest upon the lowest bedrock in these valleys, and the canyons since excavated in them are quite insignificant. Glaciation was one of the very latest events in the northern California valleys. That it was of late Quaternary age requires no argument.

The beautiful sky-blue till of the Swift Creek valley has a freshness which may be likened unto that of the Wisconsin drift-sheet in the Mississippi basin, and oxidation of its surface portion has not proceeded to any greater depth. Indeed, the youthful appearance of the whole series of glacial phenomena is identical with that which has come to be associated in my mind with the Wisconsin drift sheet. I am certain that this Sierra Costa glaciation was not the age equivalent of the Iowan or any earlier drift sheet. I am equally as certain that the glaciers disappeared a sufficient length of time ago to carry the glaciation back to the Wisconsin epoch. If there were two Wisconsin glaciations in the Mississippi basin, as some glacialists seem inclined to conclude, this California glaciation represented the later. At any rate, the glaciers of the Sierra Costa Mountains certainly were of Wisconsin age.

DISCUSSION OF CLIMATIC CONDITIONS DURING GLACIATION

It goes without saying that it was cold and there was much snow. But under this heading I wish to argue that there was no difference in the *character* of the climate between that and now — merely a lowered annual temperature and probable increased snowfall. The present climate of the Sierra Costa Mountains partakes of the general equability of the Pacific Coast region, but in addition possesses a typical alpine character. A strong contrast between the heat of night and day, *and between that of light and shadow*, is a characteristic of high altitudes where the atmosphere is clear and light, and radiation rapid. One may suffer from the heat in toiling up a sunny slope, while the air in the shadow of a peak may seem almost freezing cold. This is the condition of today at the higher levels of the Sierra Costa Mountains, and the behavior of the glaciers indicates that the same obtained in their time. They were unusually sensitive to sunlight, and shrank into the shadow of the peaks.

Gulches which faced the sun were unglaciated, altho perhaps surrounded by others in which ice accumulated to a depth of over 1000 feet. In fact, shadow was as much one of the necessary conditions of glaciation as cold and snow fall. This shows that the climate possessed the same alpine character as today. I am strongly impressed that the evidence indicates an altitude for these mountains during the Wisconsin epoch, at least as great as the present.

A POSSIBLE CAUSE OF THE GLACIAL PERIOD IN THE SIERRA COSTA MOUNTAINS

I am not prepared to argue conclusively as to why these glaciers formed in the elevated valleys of the northwestern California mountains; but I wish to present, in closing this paper, what I conceive to be a possible explanation of their existence, an hypothesis sufficient to account for all their phenomena.

The valleys where the ice accumulated are all above 6000 feet of altitude, and the sites of the main *névés* approximate a general elevation of 6500 feet above the sea. Even today the

climatic conditions at this altitude are not far removed from those favoring glaciation. The winter snow fall on the mountains is heavy, they being near the coast. On the higher peaks, light flurries of snow are often seen in July, and by the end of October, the winter's snow has set in in earnest. Storm after storm ensues thruout the winter and well on into the spring. By April 1 it is no uncommon thing for the higher mountains to be sheeted under eight, ten, fifteen, or in places as much as twenty feet in depth of well-packed snow. This melts away slowly. By June, most of it is gone; by July, nearly all; but some remains all the year on the northern slopes of Mt. Thompson and Granite Peak and in sheltered ravines of Mt. Courtney. This perennial snow lies at altitudes of about 8000 feet.

Now, in my opinion, a general uplift of the entire region to the extent of 3000 feet would be a sufficient cause for the duplication of the ancient glaciers and a restoration of the whole mountain range to its condition in the Wisconsin epoch. That would carry the summits of all the peaks above 10,000 feet, elevate the main ones, such as Granite Peak and Mt. Courtney, to 11,000 and 11,500 feet, and Mt. Thompson would tower to the altitude of 12,345 feet, comparable with Mt. Shasta. The heads of the glaciated valleys would be elevated to 9500 feet. If perennial snow lies today in small ravines at 8000 feet, how readily must it have accumulated in deep valleys over 1500 feet higher and in the shadow of peaks towering to 11,000 and 12,000 feet. Considerable bodies of snow lie all the year at no greater altitude on the sunny side of Mt. Shasta, and one may see snow on any summer day by glancing at Lassen Peak whose altitude does not much exceed 10,000 feet. Both these mountains are far from the coast, in a comparatively dry belt.

From their nearness to the Pacific Ocean, the elevated Sierra Costa Mountains must have received a heavier snow fall at a given altitude than Mt. Shasta. Also, being a group of mountains (acting like an elevated plateau) instead of a single isolated peak must have favored a lowering of the temperature and increased precipitation. Even without an added snow fall, a

simple elevation would not fall far short of reproducing the glaciers. But as the result of the uplift, it is safe to count on a greatly increased precipitation. It appears to me evident that the present conservative estimated average for the higher regions of ten feet annually might be doubled. Of this amount one half, or ten feet in thickness, might melt from the surface of the *névés* during each summer (the sun finds difficulty in removing that amount even at present altitudes). The remaining ten feet might compact into one foot of ice. Were there no loss by outflow and melting at the end of the glacier, the accumulation of one foot of ice annually would reproduce the large Salmon River glacier in 1500 years.

But a large part of the ice moved outward beyond the zone of accumulation and was lost by melting. This loss was partly compensated for by heavy snow-slides from the surrounding precipitous peaks; yet, with the greatest latitude, we must allow two or even three times as great a period as that first mentioned for the accumulation of the glacier, and the attainment of its maximum extent. I consider 5000 years as a fair estimate, and one which is not too strongly open to criticism. By a lowering of the altitude to the present and consequent increased mildness of the climate (in other words, a restoration of present climatic conditions), probably about half that time or 2500 years would be sufficient to cause the disappearance of the glaciers, and give time for the repeated slight readvances which marked their recession.

The preceding is intended merely as a suggestion, a hypothesis worthy of serious consideration. The demonstration of its reliability will depend upon external evidence of the supposed temporary uplift of these mountains. This can only be secured by careful geological work between this range and the sea, which has not yet been done.

The importance to glacialists in general of studies on the localized Quaternary glaciers of limited mountain districts lies not so much in the contrast between their alpine features and the continental features of the great North American and

European ice sheets, as in the bearing which they may have on the fascinating and yet unsettled question of the "Cause of the Glacial Period." After trying unsuccessfully to solve the problem through a study of the varied series of drift sheets in the Mississippi basin, I have concluded that we will do well to take into account such evidence as may be gathered in alpine regions of glaciation—outlines of the main sheets, we may say—for here the problem of determining climatic changes is less obscure. The suspicion is growing in my mind that the "Glacial Period" in geology, as a glacial or relatively cold epoch of time, was of world wide extent in its effects, and the absolute determination of the cause of the past accumulation of glacial ice in one section will be the key to the solution of the problem of all terrestrial glaciations.

OSCAR H. HERSHEY.

November 18, 1899.

AN ATTEMPT TO TEST THE NEBULAR HYPOTHESIS BY THE RELATIONS OF MASSES AND MOMENTA

In a paper entitled "A Group of Hypotheses Bearing on Climatic Changes,"[1] read before the Geological Section of the British Association for the Advancement of Science at the Toronto meeting in 1897, I assigned reasons for doubting the Laplacian hypothesis of the origin of the solar system, based on deductions from the kinetic theory of gases. These doubts had arisen in the course of certain atmospheric studies springing from the problem of ancient glaciation. The complete demonstration by the geologists of the far Orient that extensive ice sheets developed on the borders of the torrid zone in India, Australia and South Africa during a late stage of the Paleozoic era had made it imperative to seriously reconsider inherited views relative to the nature of the earth's early atmospheres, and this in turn forced an inquiry into the current postulate of a primitive, vast, gaseous envelope exceptionally rich in carbon dioxide; for the special heat-absorbing qualities of this constituent render it doubtful whether its presence in large amount is compatible with glaciation. The inquiry led to the application of such tests as could be derived from the doctrine of molecular velocities. As the result of such application it appeared quite impossible that a hot gaseous ring formed of the matter of the earth and moon, and having the dimensions postulated by the Laplacian hypothesis, could retain its water vapor and atmospheric gases, for its gravitative control over these was found to be far below what was necessary to overbalance their molecular velocities. It appeared very doubtful whether any of the matter of the ring, even that having the lowest molecular velocities, could be retained at the postulated temperatures and tenuity. The test seemed altogether decisive against the Laplacian hypothesis if the kinetic theory be true and the computed

[1] Published in full with supplementary tables in the JOUR. GEOL., Oct.-Nov., 1897, pp. 652–683.

molecular velocities essentially correct. However, the kinetic theory is perhaps not yet beyond its trial stages, though it is probable that the essential postulates involved in the doctrine of molecular velocities are true whatever the precise interpretation of the facts may be. There is an accord between the doctrine and the facts in the solar system which strengthens this conviction. There is an absence of atmosphere from all satellites and asteroids, so far as can be determined. The planet Mercury has little or no atmosphere. The small planet Mars has but a thin atmosphere. The Earth and Venus have considerable gaseous envelopes, while Jupiter and Saturn appear to have vast and deep atmospheres; in short, there is a general correspondence between the mass of the atmosphere and the gravitative competency of the body. In still further evidence is the essential absence of the lightest gases, hydrogen and helium, from the earth's atmosphere.[1] The former, to be sure, is chemically active, but the latter is very inert.

Notwithstanding the apparent strength of the molecular argument, other tests, based on quite independent grounds, are desirable. The more is this true since a modification of the form of the Laplacian hypothesis in which a lower temperature and a meteoroidal state are postulated deprives the molecular argument of much of its bearing. It is true that this change in the hypothesis when carried out consistently in its full application permits, if, indeed, it does not require, a revision of some of the fundamental doctrines of current geology, such as the former molten state of the earth and the long train of doctrines that hang upon this. So profound is the influence of this primal conception of a molten earth upon the dynamical conceptions and historical interpretations of the earth's evolution that every source of light bearing upon it has an importance we can scarcely realize at present.

[1] "On the Cause of the Absence of Hydrogen from the Earth's Atmosphere and of Air and Water from the Moon," by Dr. Johnstone Stoney, Royal Dublin Society, 1892. Also "Of Atmospheres upon Planets and Satellites," by the same, Trans. Roy. Dublin Society, Vol. VI, Part 13, Oct. 25, 1897; also "A Group of Hypotheses Bearing on Climatic Changes," by T. C. Chamberlin, JOUR. GEOL., Vol. V, No. 7, Oct.–Nov., 1897.

The laws of dynamics afford a firm ground of inquiry so far as they can be brought into service. As applied to mass and momentum they are rigorous, and so far as they can be covered by satisfactory computation they are decisive. The purpose of the present paper is to set forth the results of an attempt to apply these laws to the nebular hypothesis in certain ways that are more or less unfamiliar. These results are the outcome of a joint inquiry by Dr. F. R. Moulton and myself. They are a part of the results of a more or less continuous study on related themes lying on the border-land of geology and astronomy, running through the past three years. Our relations have been so intimate and our exchanges of ideas so free and so frequent that it is impossible to apportion the responsibility for the various methods adopted and the modes of carrying them out. The higher mathematical work is, however, to be credited to Dr. Moulton. It has perhaps been my function in the main to formulate problems and suggest general modes of attack, and Dr. Moulton's to devise methods of analysis and bring to bear the mathematical principles of dynamics, but this has not been uniformly so. Quite often we have proceeded by successive alternate steps in which each was the parent of its successor. In a paper in the *Astrophysical Journal* published essentially concurrently with this, by mutual understanding, Dr. Moulton discusses not only the bearings of the ratios of masses and momenta treated in this paper, but several other modes of testing the nebular hypothesis, some small part of which have been touched upon in my previous papers and some of which will be discussed in these pages later. The mathematical treatment of the present theme will be found in Dr. Moulton's paper.

For convenience and definiteness, the treatment here will be based on the Laplacian phase of the nebular hypothesis, but the conclusions will be found applicable, in all essential respects, to such meteoroidal modifications of the hypothesis as postulate a spheroidal form controlled by the laws of hydrodynamic equilibrium.

1. *Comparison of the moment of momentum of the nebular system with the moment of momentum of the present system.*—It is a firmly established law of mechanics that any system of particles of any kind whatever rotating about an axis retains a constant moment of momentum whatever changes of form or arrangement the matter may undergo by virtue of its own interaction. To make this law rigorously applicable to the solar system evolving along Laplacian lines, the influence of external and of incoming bodies must be excluded. Foreign meteoroidal matter has doubtless been added constantly to the system during its evolution, but the amount of this is assumed to be negligible; and if it were not, the law of probabilities would render its effect upon the rotation of the system an essentially balanced one, and hence immaterial. The following argument proceeds upon the Laplacian assumption that the system evolved through the operation of its own inherent dynamics. On this assumption the sum total of rotational and revolutionary momentum must have been the same at all stages of the system's evolution.

The following table gives the masses and the present moments of momenta of the several members of the solar system and of the whole system. They are taken from Darwin's paper, "On the Tidal Friction of a Planet attended by several Satellites and on the Evolution of the Solar System,"[1] and are employed in the subsequent computations. The masses assigned the planets embrace those of the attendant satellites.

Body	Masses (Earth 1)	Moments of Momenta (Darwin)
Sun -	315,511.00000	.444 Laplace's density law (Min.) .679 Homogeneous density (Max.
Mercury -	.06484	.00079
Venus -	.78829	.01309
Earth - -	1.00000	.01720
Mars -	.10199	.00253
Jupiter -	301.09710	13.46900
Saturn -	90.10480	5.45600
Uranus -	14.34140	1.32300
Neptune -	16.01580	1.80600
Solar System	315,934.51422	22.53161 (Min.) 22.76661 (Max.)

[1] Phil. Trans. Roy. Soc., Part II, 1881, pp. 516, 517.

The distribution of density in the sun is unknown. If it follows Laplace's law the rotatory momentum is .444. If it be regarded as homogeneous, the rotatory momentum is .679. This latter is certainly too large, and the former number is probably much nearer the truth, but the larger number is used in the greater part of the computations because it is more favorable to the Laplacian hypothesis.

To obtain the rotatory momentum of the ancestral nebula it is necessary to consider its form, extent, and the variation of its internal density. By hypothesis the form was an oblate spheroid, but the exact degree of polar flattening is unassigned. Simple inspection, as well as mathematical analysis, shows that a given mass of matter rotating as a sphere will have a less moment of momentum than when it takes the form of an oblate spheroid, the time of rotation and other factors being equal. If a yielding sphere be rotated it takes the spheroidal shape because that is the form of equilibrium for the added rotational momentum, and is an expression of such addition. To give the Laplacian hypothesis the benefit of every doubt, the moment of momentum of the nebula is computed on the basis of a sphere. So also to favor the hypothesis, the nebula is made to reach merely *to* the orbit of the derived planet, not to extend beyond it as is usually and necessarily assumed. In computing the rotatory momentum of the whole nebular mass just before Neptune was separated, it is assumed that it reached only to Neptune's orbit, whereas the nebular border must probably have extended some 500 million miles beyond.

As this question of the distribution of the matter from which the planets were formed under the Laplacian hypothesis has other applications, it may be remarked here that in the formation of a planet from a ring of dispersed matter the planet must assume such a point within the ring as to preserve the moment of momentum of the mass. In a symmetrical ring this point is somewhere near the center of the cross section. Though subject to some qualifications from the greater circumference of the outer part and the possibly greater density of the inner part

and other contingencies, it will be sufficiently accurate for the purposes of this discussion to assume that the planets were formed in the centers of their respective rings, and that the space appropriate to each planet reached half way to the neighboring planets.

The more important consideration, however, in determining the rotatory momentum of the ancestral nebula is the distribution of its internal density. Our method has been to compute this on the basis of the recognized laws, using in particular the formula of Lane, and to compare results with the previous determinations of mathematicians and physicists.[1]

The distribution of density in such a nebulous sphere has been the subject of investigation by Lane, Ritter, G. W. Hill, George Darwin, Lord Kelvin, and others.[2] The results reached by all are in substantial agreement, though somewhat different analytical methods were followed. In obtaining the final numerical results used in this paper, the distribution of density found by Darwin was adopted. The method of computation is given in Dr. Moulton's paper in the *Astrophysical Journal.*

When the solar nebula extended to the orbit of Neptune and embraced the matter of the whole system and had a rotation

[1] The laborious work of making the computation was undertaken by Mr. C. F. Tolman, Jr., under the direction of Dr. Moulton, and preliminary results were obtained by him, but before these had been sufficiently verified he was called to a position whose immediate requirements prevented the completion of the desired verification. For this reason, and for the obvious advantage of resting the present argument as far as possible on the computations of an acknowledged authority, results reached by Darwin, which are applicable to a gaseous or meteoroidal nebula in convective equilibrium, have been adopted.

[2] LANE: On the Theoretical Temperature of the Sun under the Hypothesis of a Gaseous Mass Maintaining its Volume by its Internal Heat, and Depending on the Laws of Gases as Known to Terrestrial Experiments, Am. Jour. Sci., Vol. XLIX, pp. 56–74, 1870.

RITTER: Untersuchen über die Höhe der Atmosphäre und die Constitution gasförmiges Weltkoper, Wiedemann's Annalen (New Series), Vol. XVI, 1882, p. 166.

G. W. HILL: Annals of Mathematics, Vol. IV, 1888.

DARWIN: On the Mechanical Condition of a Swarm of Meteorites, and on the Theories of Cosmogony, Trans. Phil. Soc., 1888.

KELVIN: On the Origin and Total Amount of the Sun's Heat, Popular Lectures and Addresses, 1891. Constitution of Matter, pp. 370–429.

equal to the angular velocity of Neptune, its computed moment of momentum was 4848.055, while the present moment of momentum is 22.7666. The unit is an arbitrary one arising from the selection of convenient initial units. In this paper, Moulton's unit is converted into Darwin's unit, for convenience of comparison. It appears, therefore, that notwithstanding the concessions to the Laplacian hypothesis by which the present moment of momentum was made too large, and the nebular moment of momentum too small, the latter is still 213 times larger than the former. The dynamical law that demands constancy of moment of momentum is not even remotely fulfilled. A more rigorous computation, following the probabilities of the case without regard to its bearings on the Laplacian hypothesis, would increase the discrepancy.

Individual discrepancies.—Not only does the law fail of realization when the present system taken as a whole is compared with the ancestral nebula, but also in a comparison between the successive nebular stages and the corresponding parts of the present system. For example, the computed rotatory momentum when the nebula extended to Jupiter's orbit, and included the Jovian mass, was 1996.420, while the moment of momentum of the present system, minus the moment of momentum of Neptune, Uranus, and Saturn, is 14.1816. The discrepancy here is more than 140 to 1.

When the nebula extended to the earth's orbit, and included the terrestial mass, its moment of momentum was 857.330. The moment of momentum of the Earth, Venus, Mercury, and the sun, by hypothesis formed from this nebula, is only .71008. In this case the excessive estimate of the sun's moment of momentum, due to the assumption of homogeneity, introduces a disproportionately large error, and yet the discrepancy is 1208 to 1. Computing the sun's moment of momentum on the basis of Laplace's law of destiny, the discrepancy is 1801 to 1.

When the nebula extended to Mercury's orbit, and included this planet's mass, its moment of momentum was 512.290, while the moment of momentum of Mercury and the sun (excessively

estimated) is 0.67979, making the discrepancy 754 to 1. On the more probable basis of Laplacian solar density the difference is 1127 to 1.

From these data it appears that there is not only a fundamental and pervasive discrepancy between the computed nebular momentum and the actual present momentum, but there is also a strange irregularity in the discrepancies themselves. A fundamental error in the analytical work, or in the assumptions on which it is based, should give a systematic error, or at least a graded series of errors. But the discrepancy shown is not systematic or even graded. Not only are the discrepancies enormously large in themselves, but their irregularities are also large. This will appear better by bringing them together into a table.

Nebular M. of M.	Present M. of M.	Ratios.
Neptunian stage, 4848.055	22.76661	213 to 1
Jovian " 1996.420	14.18161	141 to 1
Terrestial " 857.330	0.71008	1208 to 1
Mercurial " 512.290	0.67979	754 to 1

2. *Can these discrepancies be due to a radical error in the law of density?*—It is certain that Boyle's law is not rigorously applicable to gases under all conditions, and it is pertinent to inquire whether any deviation from it can account for the discrepancies which the foregoing computations reveal. The researches of Amagat[1] and others have shown the nature of the deviations within the limits of experimental tests and Van der Waals' law furnishes a basis for the theoretical extension of these results to other conditions.

Near the temperatures of liquefaction the density increases faster than the law requires. Obviously the exterior of the nebula would be effected by lower temperature than its interior and would be most influenced by this variation so far as dependent on low temperatures. As the peripheral portion carries the largest part of the rotatory momentum any increased density there through failure of Boyle's law would increase the discrepancy.

[1] WÜLLNER: Experimental Physik. Tables. Vol. I, p. 542.

In the interior of the nebula the temperatures were probably far above the critical temperatures of all known substances, and this renders it improbable that central liquefaction prevailed during the nebular stages; indeed the very dispersion of the matter into so vast a volume as the Laplacian hypothesis postulates may perhaps be taken as an implicit assertion of the dominance of the gaseous laws throughout the mass. This is certainly the view of its ablest exponents. Lord Kelvin speaking of a globular gaseous nebula (selected to represent the primitive nebula), having the mass of the solar system and a radius forty times the radius of the earth's orbit, says: "The density in its central regions, sensibly uniform throughout several million kilometers, is one twenty-thousand millionth of that of water; or one twenty-five millionth of that of air."[1] Similar determinations may be found in the more elaborate computations of Darwin for varying dimensions of the nebula.[2] We are therefore apparently not dealing with densities, even in the central parts, greater than those covered by experimental evidence.

Besides, the present distribution of matter in the solar system offers an independent argument against any great central liquefaction, until after the earth was separated at least, for, by hypothesis, the earth was formed from the extreme equatorial periphery of the nebula, but the larger part of its material is of the most refractory kinds known and would pass into the liquid and solid states early in the history of condensation. There seems little ground therefore for assuming any effective condensation of the central matter of the nebula during at least the early stages of planetary evolution.

On the other hand, experimental evidence and theoretical deductions alike indicate that under very high pressures, where the temperature is also above the critical point, the density fails to increase as fast as the pressure. As these are the assigned conditions of the central part of the nebula, any failure of the law in this direction would increase the discrepancy.

[1] Popular Lectures and Addresses, I. Constitution of Matter, p. 419.

[2] On the Mechanical Conditions of Swarms of Meteorites, and on Theories of Cosmogony, Phil. Trans. Roy. Soc., 1888.

It does not appear therefore that there are good grounds for assuming a failure of the recognized law of density in such a direction as to relieve the great discrepancy shown by the computations. In any case there is the gravest reason to doubt whether it could reach a value represented by a multiplier ranging from 140 to 1200, not to say 1800.

But even if an arbitrary attempt were made to reduce the computed moments of momenta to consistency with those of the existing system, it is not apparent how it could be attended with success and preserve self consistency. The discrepancies are:

For the Neptunian nebula - - - -	213 to 1
For the Jovian " - - - - -	141 to 1
For the Terrestial " - - - - - -	1208 to 1
(or on the more probable basis) - -	1801 to 1
For the Mercurial nebula - - - -	754 to 1
(or on the more probable basis) - -	1127 to 1

Now any deviation from the recognized law must be supposed to be consistent for analogous conditions. If therefore we assume such a modification as to bring the moment of momentum of the Neptunian nebula into equality with the present moment of momentum, we must assume that a similar modification held good for all the subsequent stages, either in the same proportion or in some systematically increasing or decreasing proportion. But the ratios succeed each other in a very arbitrary way, and the Neptunian divisor will not bring the others into accord, nor will any obvious series of divisors built systematically upon it. Were the computation extended to the other nebulæ, additional irreducible irregularities would doubtless appear.

3. *The ratio of masses to momenta.*—In the symmetrical evolution of a spheroidal nebula by secular cooling, as postulated in the Laplacian hypothesis, it is reasonable, if not necessary, to suppose there would be some systematic and rational relationship between the masses separated from time to time and the moments of momenta of these masses, for the separation was due to a common progressive cause, the acceleration of rotation. The hypothesis may therefore be tested along these lines. In

the test here applied the question of nebular density does not enter, and certain assumptions that might be made to meet the previous discrepancies are here checked.

Just previous to the hypothetical separation of the Jovian ring from the solar nebula the moment of momentum of the latter, reckoned from the present momenta of its derivatives, was 14.1816, if the sun be regarded as homogeneous, or 13.947, if the sun's density followed Laplace's law which is probably much nearer the truth. Of this, Jupiter now has 13.469. Neglecting for the present subsequent transfers of momentum, it follows that when the Jovian ring separated it carried away 13.469 / 14.182 or about 95 per cent. (94.97 per cent.) of the total moment of momentum of the nebula (or 96.57 per cent. on the more probable basis). Now the mass of Jupiter's ring was 1 / 1049 of the parent nebula, or less than one tenth of 1 per cent. It thus appears that the unqualified Laplacian hypothesis involves the implicit assertion that in the formation of the Jovian ring less than one thousandth of the mass carried away 95 per cent. of the moment of momentum. Is this possible in a spheroid of gaseous or quasi-gaseous material in convective equilibrium? One nineteen-thousandth more of the mass thrown off with an equal proportion of rotational momentum would have exhausted the supply. Apparently the minor planets had a narrow escape from not being at all.

Similar but not uniform disparities appear in a comparison of the masses and momenta of the other planetary rings with their parent nebulæ. In such a comparison also the great disparities in the planetary masses become conspicuous.

The mass of the Neptunian ring was about five thousandths of 1 per cent. of its nebula and by hypothesis it carried away about 8 per cent. of the moment of momentum of the nebula.

The mass of the Uranian ring was four and a half thousandths of 1 per cent. of its nebula. It hypothetically carried away 6 per cent. of the nebular moment of momentum.

The mass of the Saturnian ring was less than a third of a hundredth of 1 per cent. of its nebula and yet it carried away 27 per cent. of the nebular moment of momentum.

The mass of the Martian ring was three hundred-thousandths of 1 per cent. of its nebula, and yet it took away 0.35 per cent. of the moment of momentum of the nebula.

The mass of the Terrestrial ring was less than a third of a thousandth of 1 per cent. of its nebula, and it carried away 2.4 per cent. of the nebular moment of momentum.

The mass of Venus' ring was about one fourth of a thousandth of 1 per cent. of its nebula, and it carried off 1.89 per cent. of the nebular moment of momentum.

The mass of the Mercurial ring was only about one fifth of a ten-thousandth of 1 per cent. of its nebula, and it hypothetically carried off 0.12 per cent. of the nebular moment of momentum.

Not only are these ratios very extraordinary in themselves, but their relations to each other seem scarcely less remarkable. This will appear more apparent when they are gathered into a table and referred to a common unit. This unit is one one-hundred-thousandth of 1 per cent of the individual nebular mass. It will be seen that on this *proportional* basis, the moments of momenta range through a gamut of more than ten points, the proportion of Mars being more than ten times that of its neighbor Jupiter.

Ring	Percentage of mass of its nebula	Percentage of M. of M.	Percentage of M. of M. reduced to basis of .00001% of nebular mass.
Neptunian	0.00507	7.93	.0156
Uranian	0.00454	6.31	.0139
Saturnian	0.02852	27.78	.0098
Jovian	0.09530	94.97	.00996
Martian	0.0000323	0.36	.1099
Terrestrial	0.0003160	2.42	.0766
Venus	0.0002495	1.89	.0755
Mercurial	0.0000205	0.12	.0566

There seems to be no systematic variation in these. It is furthermore remarkable that, high as is the ratio of Jupiter's moment of momentum to the parent nebula, it is proportionately surpassed in most other cases.

4. *Can these high ratios of the moments of momenta of the planets to the residual nebulæ be attributed to transfer of moment of momentum*

from the sun by tidal friction?—Darwin has made familiar the principle of the transfer of the moment of momentum of a rotating body to its satellite by his classic investigation of the evolution of the earth-moon system. Applying this principle to the solar system, is it possible to explain the low rotatory momentum of the sun and the high moments of momenta of the planets by a transfer of momentum from the former to the latter?

The most obvious and tangible effect of solar tidal friction on the planets is to destroy their rotations. The patent fact that most of them still retain high speeds of rotation is a physical expression of the limitations of past tidal action.

Darwin has computed the rotational momenta of all the planets that afford the requisite data and also the revolutionary momenta of their satellites.[1] Making a generous allowance for the unknown and uncertain factors and counting in unnecessarily the orbital momenta of the satellites, the whole internal momentum of the planetary systems falls short of a thousandth part of the sun's rotational momentum computed on the minimum basis. This means that to have reduced the sun's rotational momentum from twice the present amount to the existing status, and to have transferred this to the planets, more than a thousand times the total rotatory momentum of all the planets must have been destroyed. But this would be only a slight step toward the adjustment contemplated.

To realize what might be necessary, if the foregoing nebular computations are well founded, let the matter of the solar system be converted into a gaseous nebula in hydrodynamic equilibrium extending beyond the orbit of Neptune; let this nebula be given the moment of momentum of the present solar system, and then let it contract by cooling, with the development of accelerated rotation, as postulated in the Laplacian hypothesis. An inspection of the foregoing data will show that the centrifugal force would not become equal to the centripetal force until the nebula had shrunk far within the orbit of Mercury. The

[1] On the Tidal Friction, etc., pp. 519–523.

tidal problem then becomes the dispersal of the planets from this central position to their present places.

Concerning the competency of the solar tides to alter the orbits of the planets (and hence their moments of momenta), Darwin says:[1] "It may be shown that the reaction of the tides raised in the sun by the planets must have had a very small influence in changing the dimensions of the planetary orbits around the sun. From a consideration of numerical data with regard to the solar system and the planetary subsystems, it appears improbable that the planetary orbits have been sensibly enlarged by tidal friction since the origin of the several planets." Again, he says:[2] "If the whole of the momentum of Jupiter and his satellites were destroyed by solar tidal friction, the mean distance of Jupiter from the sun would only be increased by one twenty-five hundredth part. The effect of the destruction of the internal momentum of any of the other planets would be very much less." And again:[3] "The present investigation shows, in confirmation of preceding ones, that at this origin of the moon the earth had a period of revolution about the sun shorter than at the present by perhaps only a minute or two, and it also shows that since the terrestrial planet itself first had a separate existence the length of the year can have increased but very little, almost certainly by not so much as an hour, and probably by not more than five minutes."

Aside from the quantitative difficulties there are formidable qualitative ones growing out of the proportional distances of the planets and the enormous lapses of time involved in a tidal retrogression of the planets through the postulated distances.

Conclusions.—The general result of the inquiry is to show, if we have not somewhere fallen into error, various relationships of mass and momentum which are seemingly altogether incompatible with an evolution of the solar system from a gaseous spheroid controlled by the laws of hydrodynamic equilibrium

[1] Encyclopedia Brittanica, Article "Tides," p. 380.

[2] On the Tidal Friction, etc., p. 524.

[3] Loc. cit., p. 533.

and developing by secular cooling. The argument is equally cogent against an evolution from a meteoroidal spheroid controlled by the laws of convective equilibrium, such, for example, as that made the subject of investigation by Darwin in his memoir: "On the Mechanical Conditions of a Swarm of Meteorites and on Theories of Cosmogony."

The results point to an unsymmetrical distribution of matter and of momentum. It should go without saying that we assume a nebular origin in the broad sense of the term, but the inquiry seems to show that the original form of the nebula and the mode of its development are to be sought on new lines. The foregoing data seem to constitute criteria of a rather rigorous nature to which a working hypothesis must conform. They are thereby aids in the construction of a tenable hypothesis. They seem to require the assignment of some mode of origin by which the peripheral portion of the system acquired all but a trivial part of the moment of momentum, while it possessed but a trivial part of the mass. The first suggestion of these conclusions was the possible formation of the system by the collision of a small nebula upon the outer portion of a large one, the smaller one having necessarily a high ratio of momentum to mass, while the larger one may have had little or no rotatory momentum, or even an adverse rotation. The low degrees of ellipticity of the present orbits seem to present grave difficulties in the framing of a consistent hypothesis of origin along this line, but these may not prove insuperable.

The results also naturally turn thought anew toward existing nebula for an exemplification of the evolution of the solar system. It is not a little significant that of the thousands of nebula now known no one, I believe, closely represents the annular process; certainly none represents the secondary annulation coincident with the primary. To bring the current hypothesis into consistency with observed nebular states, it seems necessary to assign it to so late a stage of concentration and to such small dimensions as to be beyond observation—at most, a hypothetical resort.

Following a purely naturalistic and inductive method, it would seem that the spiral nebulæ, whose abundance is attested by the recent notable success of Professor Keeler in photographing numerous small ones, offer the greatest inherent presumption of being the ancestral form. While present knowledge of their dynamics is almost inappreciable, the suggestions of their forms and the distribution of their matter do not seem necessarily incompatible with the criteria deduced in this inquiry.

Both these suggestions are obviously very immature, and have their sole justification in a natural reluctance to offer destructive results only—a reluctance intensified by an acute consciousness that the hypothesis against which they are directed is perhaps the most beautiful and fascinating ever offered to the scientific public.

T. C. CHAMBERLIN.

EDITORIAL

FOR more than thirty years Mr. W. F. E. Gurley, of Danville, Illinois, formerly the official geologist of this state, has been one of the most systematic collectors of Paleozoic fossils in the Mississippi valley. Not only has he gathered together what is probably the best existing collection of Paleozoic fossils of the interior states, but he has secured a large amount of valuable material from other portions of this country and from Europe. The collection has furnished much material for study to such paleontologists as C. A. White, E. D. Cope, S. H. Scudder, J. S. Newberry, Leo Lesquereaux, and Charles Wachsmüth, and many types of the species described by these men are included in it. More recently Mr. Gurley himself, associated with the late S. A. Miller, of Cincinnati, has described many new species from the collection. Aside from these types Mr. Gurley has been fortunate in securing many other types of species described by Owen and Shumard, Hall, Wetherby, and Miller.

In addition to the types in the collection, which are about 600 in number, some of its most noticeable features are the following: an exceptional series of Devonian fossils from the falls of the Ohio, including crinoids, corals, brachiopods, and trilobites; a fine series of Kinderhook crinoids from Le Grand, Iowa; an admirable series of Coal Measure crinoids from Kansas City, Missouri; a large collection of fish remains from the limestones of the Mississippi valley; an almost exclusive collection of the vertebrate remains from the Permian bone bed near Danville, Illinois, including all the types of the species from this locality described by Professor E. D. Cope; and a fine series of blastoids and cystoids. Among the foreign material a choice series of Solenhofen slate fossils and an excellent series of Carboniferous crinoids from Moscow, are worthy of special mention. These features serve to show something of the contents of the

collection, but they constitute only a small portion of the whole. The entire collection is estimated to contain 15,000 species and several hundred thousand specimens.

Through the generosity of Mr. Gurley himself, this collection has recently become the property of the University of Chicago. It will be installed in Walker Museum as rapidly as possible and will constitute the nucleus of still further growth. It will be the policy of the University to make this collection, and the future additions to it, not merely an exhibition of rare and choice fossils, but a basis of research which will be open to competent students under approved conditions. It will, beyond question, prove to be eminently serviceable in promoting appropriate lines of investigation and will thereby constitute a notable contribution to the progress of historical geology.

STUART WELLER.

Reviews

The Diuturnal Theory of the Earth; Or, Nature's System of Constructing a Stratified Physical World. By WILLIAM ANDREWS. Published by Myra Andrews and Ernest G. Stevens. New York, 1899. 8vo, pp. 551.

The consideration that might naturally be awakened by the evidences of great labor under manifest limitations embodied in this posthumous book is well nigh forstalled by the bad taste and absurd presumption of the preface by Mr. Stevens in which Mr. Andrews is styled "the greatest scientist America has produced" who "left comparatively little to be accomplished," and so forth.

"The Diuturnal Theory of the Earth" consists essentially of the assumption that "the north terrestrial polar point is taken within 30° to the south siderial polar point, and returned to within 60° of the point under the north star, from whence it started," and that the essential features of geological history are due to this. This polar movement is assumed to have taken the form of a spiral migration involving "six polar transitions" across the eastern and western hemispheres. There is no serious attempt to show that such a movement was a fact either by inductive evidence or deductive theory. The author's method seems to have been the pre-scientific one of developing a conception essentially *ex nihilo* and of interpreting the phenomena by means of it. The book is interesting as an exhibition of great labor enthusiastically devoted to the broad themes of geology under limitations that precluded either the mastery of the facts needed for induction or the dynamic principles necessary for deduction. If the filial regard which has given it to the world a dozen years after the author's death had been content to rest it on the modest basis of the thoughtful efforts of a studious man working under conditions that precluded success, it would have been wiser than to put it forth with the pretentious assumption of having "made the patchwork of geology into a complete science."

T. C. C.

Memoirs of the Geological Survey of the United Kingdom. The Silurian Rocks of Britain. Vol. I, Scotland, 1899. By B. N. PEACH, JOHN HORNE, and J. J. H. TEALL.

This publication, which comprises the first volume of a proposed monograph on the Silurian rocks of Great Britain and Ireland, treats of the Silurian formations of Scotland in a praiseworthy degree of completeness. It is a work destined to maintain the high standard of excellence attained by the British Survey Reports.

The opening chapter is devoted to the physical features of the Silurian region. The region in general comprises the Southern Uplands which, lying between the Central Lowlands on the north and the Cheviot Hills and Solway Firth on the south, stretch from the North Sea to the Irish Channel. The topography of the region varies from the uniformly smooth or undulating types in the central and eastern parts to the rugged craggy type of the southwestern part. The Uplands vary in height from one to two thousand feet. The northern border is traversed by an extensive fault which lets down the Devonian and Carboniferous rocks of the north to form the surface of the Central Lowlands.

The succeeding chapter is devoted to the history of previous researches among the rocks of this district. These researches cover a period of more than a century, and have engaged the attention of many of Britain's foremost geologists of the past and present. Beginning with Hutton among others are the names of Hall, Fairplay, Nicol, Harkness, Murchison, Sedgwick, Ramsay, A. Geikie, J. Geikie, and Lapworth, besides the names of the authors, Peach, Horne, and Teall. To Lapworth is given the credit of establishing by paleontological and stratigraphical achievements the true order of succession of the Silurian strata. His studies of the sequence of the Silurian graptolite faunas made possible the correction of erroneous estimates of the thickness of the beds and enabled the structure of the region to be worked out in the most complicated areas.

The stratigraphy and the tectonic arrangement of the rocks are set forth in the third chapter of the volume. The Lower Silurian series is divided into the Arenig, the Llandeilo, and the Carodoc formations. The Arenig strata consist of cherts, mudstones, shales, and volcanic tuffs interbedded in places with tuffs, lavas, and agglomerates, associated with intrusive masses comprising serpentine, olivine, enstatite

rock, and gabbros. Many of the volcanic eruptions took place under submarine conditions. There were also periods of quiescence, during which fine sands and mud containing fossils were deposited.

A subsidence of the sea floor ushered in the next period, the Llandeilo. The rocks of this formation are radiolarian cherts and mudstones which were deposited in clearer waters than the rocks of the Arenig. The rocks of the Carodoc are shales, conglomerates, and limestones, implying variable conditions of deposition.

The Upper Silurian, it is said, is separated from the Lower Silurian by both physical and paleontological changes. But there appears to be no great paleontological break such as characterizes the separation of the Ordovician from the Silurian on the interior of the American continent. The transition from the Lower Silurian to the Upper Silurian types is a gradual one. This province may constitute one of harbors of refuge spoken of by Professor Chamberlin in his discussion of the source of provincial faunas. It would correspond, then. on the American continent, to the embayment at the mouth of the St. Lawrence. The following table will serve to compare the distribution of the Brachiopods common to the two countries, Scotland and America:

	Scotland		America	
	Lower Silurian	Upper Silurian	Ordovician	Silurian
Atrypa reticularis	x	x	..	x
Atrypa marginalis	x	..	..	x
Cyrtia exporrecta	..	x	..	x
Leptaena rhomboidalis	x	x	x	x
Plectambonites transversalis	x	x	..	x
Platystrophia biforata	x	x	x	x
Rafesinesquina alternata	x	..	x	..
Bilobites bilobus	x	x	..	x
Dalmanella elegantula	x	x	..	x
Dalmanella testudinaria	x	..	x	..
Orthis tricenaria	x	..	x	..
Pentamerus oblongus	..	x	..	x
Uncinulus stricklandi	x	..	..	x
Spirifer crispus	x	x	..	x
Spirifer radiatus	..	x	..	x
Rafesinesquina deltoidea	x	x	x	..
Rafesinesquina imbrex	x	..	x	..
Total of species	14	11	7	12

This table shows that of the fourteen species occurring in the Lower Silurian of Scotland but one half that number are represented in the American Ordovician, the other seven species appearing in the American Silurian. As most of these species occur in the last member of the Lower Silurian, the Carodoc, it is probable that this formation forms the transition zone between the Ordovician, as we know it, and the Silurian.

The Upper Silurian series is divided into the Llandovery, the Tarannon, the Wenlock, the Ludlow, and the Downtonian. These formations consist of mudstones, limestones, grits, graywackes, and conglomerates. The Downtonian which hitherto has not been recognized as a part of the Silurian is probably the equivalent of the Waterlime formation of our own country. It contains a fauna consisting of Ostracoids, Eurypterids, and fishes similar to the fauna of the Waterlime formation. This formation immediately underlies the Old Red Sandstone.

The economic products of the Silurian formations are lead, iron, copper, antimony, manganese, zinc, mispickel, silver, and gold, besides building materials, road-metal, and hone-stones.

Other chapters in the book are devoted to contact-metamorphism, and to the granites and associated igneous rocks.

W. N. LOGAN.

Genesis of Worlds. By J. H. HOBART BENNETT. Springfield, Ill.: H. W. Rokker, printer, 1900. Pp. 345.

This work does not need serious review from the point of view of science. It is the product of a mind deeply interested in the problems of cosmogony and apparently ready to accept the demonstrations of science, but yet still under the dominance of the traditional anthrophic mode of thought. It betrays throughout a serious lack of firm grounding in the elements of the sciences involved in the subjects under discussion, a grounding absolutely necessary to their successful treatment. The mode and style of the book may be illustrated by the following quotation from page 3:

> Inquiring minds have a propensity for tracing things to a first cause, and would ask from whence came the great nebula. It could not have sprung into existence already formed. It had an origin which is worthy of a most careful investigation, for it is one of a class that is represented by thousands

of similar bodies in the heavens. May not a conjecture of its antecedents be properly presented here? It is that when the great Creator would form a new system of worlds, having allotted a district of suitable form and dimensions for the purpose, he changes the primordial matter in it from a gaseous condition, in which it had been under the law of repulsion, into cosmical dust, by which slight change it became subject to the law of gravitation.

And the following from pages 72 and 73:

Any matter erupted from the sun can return to it again, as it does constantly from its prominences. But there seems to be a repulsion between all comets and the sun. They are attracted toward it, but never to it. After one revolution the reason may be given that they have established orbits. But that reason does not apply to the first approach. Any other bodies gravitating toward the sun from the depths of space would fall directly upon it. But cometary matter seems to be governed by an unknown law, a law of gravitation limited. There is attraction at a great distance, but repulsion on near approach. Is it not evident from the following quotation? "The great comet of 1843 passed within three or four minutes of the surface of the sun, and therefore directly through the midst of the corona. At the time of nearest approach, its velocity was three hundred and fifty miles a second, and it went with nearly this velocity through at least three hundred thousand miles of corona, coming out without having suffered any visible damage or retardation" (NEWCOMB'S *Popular Astronomy*, p. 251).

Was not that a clear case of mutual shrinkage or gathering of skirts as two persons would gather their delicate robes to avoid contact when passing too near each other?

Occasionally the style falls off to this:

This hypothesis presents, in a greater degree than any explanation heretofore offered, the elements of possibilities in the tissue of forces and their observed effects. Indeed those effects demand a reasonable exposition of producing causes.

The author attempts to solve some of the fundamental problems of geology by giving enormous magnitude to the rendering and triturating effects of the descent of the waters of the supposed primitive vaporous atmosphere upon the assumed hot earth. Respecting this he says:

The inquiry must arise in every thoughtful mind, to what depth will the breaking of the rocky crust extend? What can arrest the destructive action of the water? Will the weight of the débris affect it at the depth of one mile, or two miles, or three miles? No, nothing can resist the explosive power of steam. It opens the way and keeps it open for the

downward progress of water. Nothing can arrest the destruction of the rocky crust so long as there is rock to be broken. The entire solid crust of the earth must be transformed, must be rent into fragments. The water reaches the molten mass below and can go no farther. . . . .

Again the phenomenal changes and the condition of the earth's crust embarrass our powers of description, and even conception. The water having reached the molten mass below the fragmental crust, could go no farther. It had reduced the temperature of the upper surface more nearly to that of boiling water, while that of the molten mass below the broken crust was nearly forty-four hundred degrees higher. The entire mass, thirteen miles in depth of débris and water, is kept in violent motion by the resistless power of steam over the entire surface of the globe.

On this "true basis," in negligence of the most obvious limitations of a well-recognized action, the author builds theories of elevation, vulcanism and stratification, and assumes that he has solved some of the great problems of geology.

Those who are not well versed in what is established will read the book at much risk of mixing needless error with truth, while those who are so versed will probably find it interesting chiefly as a psychological study.

The book is pervaded by an ostentatious piety of the type prevalent in the last century, which is liable to produce a moral effect quite opposite to that intended. True reverence is best displayed by refraining from presuming to know the mind and purpose of the Infinite and by scrupulously dissociating one's imperfect notions from all connection with Omniscience. T. C. C.

Text-Book of Paleontology, by KARL A. VON ZITTEL, translated and edited by CHARLES R. EASTMAN. Vol. I, Part II, pp. 353–706, with 883 wood-cuts. Macmillan & Co., 1899.

After an interval of more than three years since the appearance of Part I, the invertebrate portion of Zittel's Paleontology is at last brought to a conclusion. The plan and scope of this work was discussed at length in a review of Part I, which appeared in this JOURNAL for October 1896; hence it is only necessary to repeat here that the English edition is a composite production, much of Zittel's text being discarded and replaced by original contributions from a dozen different authors, whose names are given on the title-page.

The Grundzüge der Paläontologie, which forms the basis of the present work, is an essentially modern, useful, and very compact treatise. It compasses within 900 odd pages the whole field of paleozoölogy, rather more than one half of the space being devoted to invertebrates. The descriptions of genera are brief but to the point, the illustrations numerous, and the arrangement simple and well-balanced. These are salutary features for any elementary text-book to possess, and the writings of von Zittel have set a high standard for other authors to emulate.

As compared with the original, we note in the first place that the English edition devotes about 200 more pages to the invertebrates, and is enriched by nearly 100 new figures. Over 4600 generic names are enumerated in the index, being about 1200 in excess of the invertebrates treated in the German edition. The amount of enlargement is therefore considerable, and the new genera introduced are mostly those which are of importance in American and British strata.

All the generic diagnoses are of necessity very brief, and large numbers of names are cited without definition, simply as an index to their family position, or degree of family differentiation. Typical or otherwise interesting forms are treated more at length, and in some instances type-species are listed; but the definitions of families and larger groups are as a rule succinctly yet carefully stated. The book serves as an excellent guide for orientation over the different groups and as a catalogue of the more important genera, but does not permit of the identification of less important genera without the aid of special literature. In compensation for this, copious bibliographies are inserted under nearly every caption, those for the Cephalopods and Trilobites being especially complete and all of them brought strictly up to date.

Many radical changes are to be observed in the classification, the responsibility for which, we are told in the preface, lies with the revisers of the different sections. The rearrangement of Pelecypod families and genera by Dr. W. H. Dall is in accordance with the latest conceptions of this eminent conchological authority. Great emphasis is laid by Dr. Dall on the distinctness of family groups, and many well-known genera are taken by him to represent types of new families, or subfamilies. Nor is Dr. Dall alone in this tendency toward elevation of families out of generic characters; it seems to be becoming more and more the fashion in all branches of systematic biology, and probably

the most remarkable illustration of all is to be seen in Professor Hyatt's new classification of Cephalopods. The chapters on Nautiloids and Ammonites, occupying 75 pages, have been entirely rewritten by Professor Hyatt, and represent in epitome a life work expended on the study of these groups. The system followed was proposed in outline at the Boston meeting of the American Association, two years ago. Its essential feature consists in the elevation of the three leading "genera" of von Buch, *Goniatites*, *Ceratites*, and *Ammonites*, together with the Clymenoids of Gümbel, into as many different suborders, and in addition to these, several entirely new ones are recognized among the Goniatites and Ammonites. A large number of genera are made the types of independent families, and the prevailing feature throughout is the comparison of young stages of specialized forms with the adult of primitive types. As the entire life history of Ammonites and other groups are recorded in the progressive changes taking place in the shell, this class of organisms is especially well suited for comparative investigations based on the principle of accelerated development.

The chapter on Trilobites is from the pen of Professor C. E. Beecher, our leading authority on this group. The treatment is much fuller than in the original, and a considerable number of new figures are added. As in the Ammonites it is of prime importance to compare the ontogenetic stages, and this furnishes the key to the new classification of Beecher, since adopted by Cowper, Reed, Bernard, and others, although opposed by Pompeckj. Trilobites are here accorded the rank of a separate subclass, all other crustacean forms being set off against them under the title of Eucrustacea. The latter have been revised for the present work by Professors J. M. Clarke and J. S. Kingsley, with the exception of the Ostracoda, which are accredited to Mr. E. O. Ulrich. A noteworthy point consists in the removal from Crustacea of the Merostomata, including Limulus, the Eurypterids, etc., and associating them with the Arachnids under the head of the *Acerata*, of Kingsley. This step, it is believed, will eventually be acquiesced in by most specialists on these groups. Altogether, the chapters on Arthropods show evidence of most careful revision, and are well-balanced as regards space.

We come lastly to the chapters on Arachnids, Myriopods, and Insects, which have been revised and slighly enlarged by that indefatigable paleoentomologist, Professor S. H. Scudder. Save for being

simpler and briefer, the treatment is much the same as that followed in the *Handbook* of von Zittel, the chapters in question having been prepared for that work by the self-same author. Here also new figures are inserted, a very striking one being Brongniart's restoration of *Meganeura*, a dragon-fly having an expanse of 30 inches between tips of wings. The book concludes with a complete index of genera and subgenera.

The present edition of the von Zittel places in the hands of every English-speaking student a good elementary text-book that has long been needed. It is significant that in the "Eastman translation" so much American material has been introduced, and that so much revision has been done by American specialists.

Regarding the work as a whole we may repeat what was said of the first part, that educators in general owe to Dr. Eastman a deep debt of gratitude for providing our college and higher schools with a "translated, revised, and enlarged edition" of the best manual of paleontology that has ever been written. Professor von Zittel is to be congratulated, not only for the improvement presented by his new elementary text-book, but also, as shown by the results, for having entrusted the preparation of the translated edition to such excellent hands. CHARLES R. KEYES.

The Gold Measures of Nova Scotia and Deep Mining. By E. R. FARIBAULT. Canadian *Mining Review*, March 1899, Pp. 11, with 6 plates.

E. R. Faribault, of the Canadian Geological survey, has lately announced the results of fifteen year's work on the gold measures of Nova Scotia. These results are of great interest, both from a scientific and economic standpoint.

The gold measures of Nova Scotia are confined to the metamorphic Lower Cambrian quartzites and slates, forming a belt along the Atlantic coast from 10 to 75 miles wide. Intruding these rocks are large masses of granite occupying nearly a third of the superfices of the province. These were intruded in Silurian time, after the folding of the strata and deposition of the gold-bearing quartz, and need not be considered. The originally horizontal quartzites and slates have been folded into a series of huge undulations roughly parallel with the seacoast. The amplitude of the folds varies considerably, but

the average is about three miles. A section of 35 miles across the gold measures gives eleven anticlines. These folds have been greatly flexed in a direction transverse to the closer folding, so that they form long domes. In the folding, the upper strata have slipped upward on the lower strata, these movements taking place largely along the soft slate layers between the hard quartzite layers. This has resulted in compression along the sides of the folds and the formation of openings along the crests.

Gold-bearing quartz has been deposited in the openings near the crests of the domes formed by the slipping of the layers. The veins thus deposited thin out rapidly along the limbs of the folds, but keep their size along the pitch for some distance, though finally pinching out. Where the folding has been close and the legs of the anticline form an angle of less than 45°, the large bodies of quartz on the anticline are called *saddle reefs*, the name given to such formations in Australia.

As yet no general operations have been carried on to any depth through the arch core of the folds in Nova Scotia, although at various places a number of veins have been found. However, from analogy with the Australian gold-bearing veins occurring in a similar manner, it is believed that the quartz veins in Nova Scotia will be found to recur many times in depth.

The laws governing the position and extent of the zones of quartz veins, as well as the laws governing the position and extent of the "pay streaks" within the veins, are given in detail.

This work of Mr. Faribault's will be of immediate practical advantage to mining men, some of whom have already testified to its accuracy and value. It is another instance, lately of frequent occurrence, of geological work done from a purely scientific standpoint having direct economic value.

From a scientific standpoint also, the results are of interest as illustrating a principle of ore deposition. In many districts, and particularly in the Lake Superior District, it has long been known that ore deposits were partial concentrates in pitching troughs by decending waters. Van Hise has lately enunciated the principle that the openings in arches or pitching folds are favorable places for the concentration of ore deposits by *upward moving waters*. The formation of the gold-bearing veins of Nova Scotia seems likely to have occurred in this way.

C. K. L.

Maryland Geological Survey, Vol. III, Baltimore. The Johns Hopkins Press, 1899.

This volume consists of the application of geology to the "permanent and economical improvement" of the roads of Maryland. It consists of 461 pages and 80 pages on "Laws of Maryland relating to highways." There are 35 plates, including 14 maps, and 38 figures.

The state geologist, Professor William Bullock Clark, contributes the Preface, Part I, Introduction, and Part II, "The Relations of Maryland Topography, Climate and Geology to Highway Construction." The author discusses the "dependence of the highways upon the surface configuration of the land," and their dependence upon the underlying formations; the effects produced upon the roads by temperature changes, precipitation and winds. He gives the areal distribution of the various geological formations of the state, accompanied by a map, and with a hint to roadmasters to make use of the information. Then follows a discussion of the road materials of the state and their relative values for road building.

Part III, "Highway Legislation in Maryland, and its Influence on the Economic Development of the State," is contributed by St. George Leakin Sioussat.

Part IV, "The Present Condition of Maryland Highways," and Part V, "Construction and Repair of Roads," are by Arthur Newhall Johnson.

The condition revealed in Part IV amply justifies the Survey in its undertaking to direct attention to the need and the methods of improvement. Yet Maryland has some excellent highways, and the average condition of its roads is perhaps as good as in most of the states. On the other hand Massachusetts and Connecticut are states which are noted for their good roads. In Part V Mr. Johnson gives practical instruction on grading, drainage, and surfacing which will be of great service in road-building,

The following Parts, VI, VII, VIII, are by Harry Fielding Reid. Part VI treats of the "Qualities of Good Road-Metals and the Method of Testing them." In this chapter Professor Reid deals with the following series of laboratory tests of materials, viz., microscopic test; abrasion test; crushing test; cementation test. The results of these tests upon various rocks are illustrated. Part VIII, relative to "The Advantages of Good Roads," is adapted to awaken an interest in road improvement.

If the people of Maryland shall become convinced that, in addition to incidental advantages, "a sum in the neighborhood of three million dollars would be annually saved by improving the important roads of the state," there will be no difficulty in getting appropriations for road building and repairs. The volume will exert a wide influence for the betterment of the roads of the country. As a piece of bookmaking it is exceptionally good. The type is clear, the illustrations are apt and well-made. The Survey is to be congratulated upon presenting in such excellent form a volume replete with valuable information and suggestion.

JAMES H. SMITH.

Maryland Weather Service, Vol. I, Baltimore. The Johns Hopkins Press, 1899.

The Maryland Weather Service is conducted under the auspices of the Johns Hopkins University, the Maryland Agricultural College and the U. S. Weather Bureau.

In Part I, Introduction, Professor William Bullock Clark gives a brief history of the State Weather Service and presents "lines of investigation pursued by the Service." These are topography, physiography, meteorology, hydrography, medical climatology, agricultural soils, forestry, crop conditions, flora, and fauna. He also enumerates the previous publications of the Service.

Part II consists of "A General Report on the Physiography of Maryland, by Cleveland Abbe, Jr. Professor Abbe discusses physiographic processes in general and takes up briefly each of the physiographic provinces of the state. A study of stream development of the Piedmont Plateau leads to the conclusion that [1] "The streams of the eastern division of the Piedmont Plateau have been superimposed from the formerly more extensive Coastal Plain cover."

Thus the explanation of McGee is confirmed by detailed field work—at least in the eastern part of the plateau. On page 132, Professor Abbe uses the phrase "Topographic Valences of the Rocks." The word "valence" in this connection is not defined, but immediately following the heading quoted the author speaks of the "different degrees of resistance which they [rocks] offer to weathering and erosion." These resistances appear to be what is meant by the term "valences." Since valence is used in a quite different, but definite,

[1] P. 216.

sense in chemistry; and since it has still another meaning in biology, we doubt the wisdom of giving the word a third technical meaning in geology. And if it means resistance to denudation the coining of a new term does not seem to be demanded.

Part III consists of a "Report on the Meteorology of Maryland," by Cleveland Abbe, F. J. Walz, and O. L. Fassig. Professor Abbe takes up Dynamic Meteorology and its Applications ; Climatology and its Aims and Methods, and Apparatus and Methods. Among many suggestive topics we note with approval the emphasis put upon "Paleoclimatology" — a subject that is receiving increasing attention on the part of geologists. Professor Abbe strongly states the case when he says,[1] "Geology is primarily a study of the influence of the overlying atmosphere upon the earth beneath. It is, therefore, an essential part of the study to understand the climates and the changes in climate that have prevailed since the earth began its annual course around the sun and its diurnal revolution around its axis. The study of modern climates must be considered by the geologists as simply an introduction to the equally important study of ancient climates and the work done by them." Dr. Fassig presents "A Sketch of the Progress of Meteorology in Maryland and Delaware." Mr. Walz gives an "Outline of the Present Knowledge of Meteorology and Climatology of Maryland." The weather maps, showing types of weather in various places and seasons are well selected and are very instructive. There is a chart showing normal temperature and pressure for Maryland, including Delaware and the District of Columbia for each month of the year; also one each for spring, summer, autumn, winter and for the year. There are also many tables for reference.

The volume is a handsome one of 566 pages, 54 plates, some of which are colored, and 61 figures. All of the illustrations except Plate XXXV are pertinent to the subject discussed and add much to the value of the volume. Plate XXXV is a picture of the office of the Weather Bureau at Baltimore. It adds nothing of scientific value and would therefore better have been omitted. It seems ungenerous to mention so small a matter, for the volume is presented in an almost faultless form both as to subject-matter and as to mechanical execution.

JAMES H. SMITH.

[1] P. 304.

Principles and Conditions of the Movement of Ground Water. By FRANKLIN HIRAM KING, with a theoretical Investigation of the Motion of Ground Waters, by CHARLES SUMNER SLICHTER. Ext. Nineteenth Ann. Rep. U. S. Geol. Survey, Part II, 1899, pp. lxi + 384.

This important paper bears throughout evidences of the painstaking industry that marks all of Professor King's work. It deals first with general considerations relative to the amount of water stored in the ground in different kinds of rock. For the Dakota sandstone he assigns 15 to 38 feet of water for every 100 feet in thickness of the rock. The water in the Potsdam sandstone of Wisconsin and adjoining states he makes equivalent to an inland submerged sea having a mean depth of 50 to 190 feet of water for the area occupied. In regard to the superficial soils and sands, Professor King gives more detailed data, as this lies in his special field of investigation. A saturated sand carries from 20 to 22 per cent. of its dry weight of water, while the soils and clays range from these values all the way up to 40 and even 50 per cent. of their dry weights. "Since a cubic foot of dry sand weighs from 102 to 110 pounds, while soils, clays and gravels range between this and 79 pounds, we have a ready means of expressing quantitatively the water which is continually stored in this mantle of loose material when it lies below the plane of saturation." In a table of actual determinations where loamy clays and very fine sandy soils are involved, 2 feet of water in 5 feet of soil below the horizon of saturation are shown. When soil does not lie below the plane of saturation it usually contains 75 per cent. of the amount required for full saturation, except during dry times when a surface layer of one to five feet thick falls below this. Even where the plane of saturation lies below a large thickness of soil there is still a large storage capacity for water.

In rocks other than sandstones and soils the percentage is usually very much smaller. Its cumulative magnitude is indicated by the statement that so small an amount of water as 0.0023 of the weight for 5000 feet of the earth's crust is large enough to form a continuous sheet about the globe 30 feet deep. It is believed that water penetrates the crust to depths even exceeding 10,000 feet. Reckoned at 1 per cent., with a specific gravity of rock of 2.65, the amount contained would be a layer 265 feet thick. Of course the amount in the upper horizons is

relatively large and that in the lower very small. An estimate of this kind gives an impression large or small according to the point of view. Regarded by itself, it is large, but compared with the whole hydrosphere it is but a small factor and does not very appreciably add to the oceanic volume. It probably does not amount to so much as the probable error in the estimation of the volume of the ocean and other superficial waters. If the water of hydration be added to it, the statement may not improbably still hold true.

In the treatment of the general movements of the ground water three categories are recognized: (1) Gravitative, (2) thermal, and (3) capillary movements. The oscillations in the flow of springs and artesian wells are illustrated by autographic records and their relations to barometric changes demonstrated. Even the sudden barometric changes accompanying a shower are sometimes sharply recorded. Diurnal changes in temperature are shown to effect the rate of seepage. This is attributed chiefly to the indirect effect of the temperature through the expansion of the gases in the soil. Movements of ground water are ascribed to rock consolidation and crust deformation. Of the 25 to 50 per cent., by volume, of water inclosed in the sediments, when first laid down, a considerable part is forced out as the sediments settle into greater compactness, and finally pass into indurated rock. By an ingenious device on automatic flow from the base to the top of a cylinder of settling sediments was secured against a head of six inches. In the dynamic consolidation of rocks, a still larger per cent. of the inclosed water is forced out. The growth of grains and the filling of pore-spaces is a concurrent source of expulsion of water. Limestones as now taken from the quarries have, as a rule, a pore-space varying from less than 1 per cent. to 7 or 8 per cent. at most; so that the final formation of every 1000 feet of compact limestone means an expulsion of water from these beds during the process of growth and consolidation amounting to not less than one fourth, and possibly as much as one half, of the present volume of the rock.

For the capillary movements of ground water recourse must be had to the paper itself, as the tables cannot be briefly and adequately summarized.

The configuration of the ground water surface is illustrated by contour maps and the flow dependent on this configuration diagrammatically indicated. The changes in the configuration that result from precipitation are shown by tables and by diagrams.

Then follows an account of an elaborate series of investigations of the flow of water through soils, sands, rocks, and other porous media. These are much too extended to be reviewed in detail. They furnish data of prime importance to studies in irrigation, water supply, and various other inquiries that involve the size of grain, the pore-space, and the various elements of resistance to percolation. The industrial as well as the scientific value of these determinations, with which are collated those of others, is obvious.

The value of the experimental study of Professor King is greatly enhanced by the theoretical investigation of the motions of ground water by Professor Slichter. The treatment is mathematical and can be read only by those who are familiar with its elegant language. The excellent illustrations, however, translate some of the more vital parts into the vernacular. Those which relate to the interferences of flows into artesian and other wells are especially instructive.

T. C. C.

Les Lacs Francais. Par ANDRÉ DELEBECQUE. Ouvrage couronné par l'Academie des Sciences. 436 pp., 22 plates, and 153 figures in the text. Accompanied by an atlas of 10 maps. Paris: 1898.

This elaborate work is divided into ten chapters, and a brief outline is here given of the substance of each:

I. *Distribution.*—Most of the lakes of France are in the mountains, the Alps, the Juras, the Vosges, and the Pyrennees; but there are some in the central plateau, some along the coasts, and still others which do not admit of ready classification. The total number of lakes given is between 460 and 470, but many of them are so small that in our own country they would be called ponds.

II. *Depth.*—The second chapter has to do with the depth of the lakes, and the chartings of the soundings.

III. *Description.*—The third chapter is a description of the principal lakes, the description taking account of the depth, the area, the position, etc. Contour maps of the basins of more than forty lakes are given on the plates. Of lakes more than 25 meters deep, there are thirteen in the Alps, eleven in the Juras, two in the Vosges, eight in the central plateau, twelve in the Pyrennees, and one on the coast of the Mediterranean, forty-seven in all. Of lakes more than 1000

hectares (approximately four square miles) in area, there are in the Alps two, in the Juras one, along the Atlantic coast four, and along the Mediterranean coast two. Even of lakes more than 250 hectares in area (approximately one square mile) there are but thirteen. It will be seen therefore that most of the lakes are very small. The tables show that the depth of many of them is great in comparison with their area.

IV. *Topography.*—The fourth chapter deals with the character of the topography and relief of the lake bottoms. Few of the lakes have great depth. Lake Geneva has a maximum depth of $\frac{1}{237}$ of its length and $\frac{1}{64}$ of its width, but these ratios are exceeded by many of the smaller lakes. The deepest lakes in proportion to their area are in the Pyrennees. Here Lac Bleu has a depth of 120 meters with an area of but 47 hectares. In the lake bottoms are recognized (*a*) the marginal plains, partly wave cut and partly wave built; (*b*) the tallus slopes (a talus slope of 87° runs down to a depth of 42 meters in one case, and a slope of 63° to a depth of 100 meters in another), and (*c*) the bottom flats. In the large lakes the sensible flat (or flats) at the bottom is some considerable fraction of the total area. In Lake Geneva the bottom flat of an area one twelfth of the total area of the lake has a relief of less than five meters. These flat bottoms are naturally more distinct in the large lakes than in the small ones. Certain more or less accidental features are recognized in the topography of the lake bottoms. Here are classed deltas, submerged valleys, ravines, hills and islands and funnels. The latter are rare, and represent either places where springs enter the lake, or where sub-surface drainage escapes. Two or three remarkable instances are cited, especially in Lac d'Annecy.

V. *Nature of the bottoms.*—The nature of the bottom is the topic of the fifth chapter. The bottom consists in part of alluvium, and in part of the rock in which the basin occurs. The alluvial material is found to vary both microscopically and chemically with the nature of the rock of the basin. Numerous tables of results are given. The following conclusions are reached: (*a*) The material at the bottom of the lake varies with the rock. In limestone basins calcareous matter dominates, while in basins in siliceous rocks, quartz is most abundant. (*b*) The mean composition of the sediment in the lake is not the same as the mean composition of the rocks in the basin. For example, the sulphates are essentially absent in certain lakes whose

affluents flow over gypsum, or whose shores are partly of gypsum. On the other hand, sulphuric acid is found in small quantity in lakes where there is no gypsum adjacent. Again, calcium is abundant in basalt, but not in the sediment in lakes in basaltic regions. Alkalis are plentiful in granitic rock, but only sparingly present in the lakes in granitic basins. The alkalis and alkaline earths are carried off in solution, chiefly as carbonates, while the silica stays behind and is thus concentrated. (*c*) The composition of the sediment varies in different parts of the same lake.

Sediment is absent in the bottom of the lakes where the slope is too steep for it to rest, in general where the slope is over 45°, and where local conditions have prevented deposition, as where springs enter or where drainage flows out. Sediment is also absent where currents have been effective at the bottom.

VI. *Supply and loss.*—A chapter is devoted to the supply and loss of water, and to the variations in the levels of the lakes. An interesting section is given to the average length of time which water stays in lakes. This is determined from the volume of the lake, and the rate of outflow. Thus in Lake Geneva, it is found that the average stay of water in the lake is eleven years and seventy-three days; in lake d'Annecy three years and one hundred and thirteen days; in Lake Chaillexon five days. Many other calculations are given, all of which tend to show that the duration of the stay of water in lakes is extremely variable. Lakes with surface outlets are found to change their levels but slightly. Data on this point seem somewhat imperfect, but the maximum known fluctuation in the case of lakes having surface outlets is three meters. In lakes having sub-surface outlets, fluctuations of level are far greater. They appear also to be greater for small lakes than for large ones. Thus the level of Lake Chaillexon between August 19, 1892 and December 31, 1895, fluctuated sixteen meters.

VII. *Temperature.*—The tables of temperature given show that the water at the bottoms of the deep lakes varies very little, and that it is near the temperature of greatest density all the time. The tables show that in most lakes there is a well-defined zone which separates the warm (during most of the year) water above from the cold water below, the transition being usually rather abrupt. This zone of transition is rarely more than twenty meters below the surface, and sometimes not more than ten. The causes determining temperature are considered. Aside from (*a*) climate, the effect of which is obvious, (*b*) the average depth, (*c*)

the form and orientation of the lakes, and (*d*) the sources of supply, influence their temperature. The form and orientation of the lakes is of importance in connection with the winds. Lakes which are oriented so as to allow winds to exert their most important influence in the generation of currents, have their temperature equalized in the vertical sense, through the return currents. Circulation is thus shown to be of more importance than conduction in equalizing the temperature between top and bottom. The rôle of affluents in determining lake temperatures is very variable. It depends on the size of the lake, the average stay of the water in the lake, and the nature of the affluents themselves. Following Forel, the author emphasizes the paradoxical fact that the waters of the glacial Rhone raise the temperature of Lake Geneva, the temperature of the river being notably above that of the lower part of the lake at all times, while the large amount of sediment in the river water so increases its specific gravity as to cause it to descend much below the zone of lacustrine temperature corresponding to its own. Sub-surface affluents exert an important influence in their immediate surroundings, or, if the lake be very small, on the whole volume of water. The temperatures of these affluents being essentially constant, the temperature of the lake is differently affected by them in different seasons. Lakes are classified by the author, following Forel, on the thermal basis, as *tropical*, *temperàte*, and *polar*. The tropical lakes are those whose surface waters do not reach 4° C.; the temperate lakes are those the surface waters of which are sometimes below and sometimes above 4°; while the polar lakes are those whose surface waters never rise above 4°. Of the first class the larger part of Lake Geneva, and certain salt lakes near the shore are the only representatives. To the second class most of the lakes of France belong, but there are a few representatives of the third class in the Pyrenees, and in certain other high altitudes.

Chapter VIII deals with the *transparency*, *color*, etc., of the lakes. The lakes are partly blue (few), partly green (the larger number), and partly yellow (a large number.) The color is found to be influenced by (*a*) the dissolved organic substances, such as humic and ulmic acids; (*b*) the presence of vegetable and animal organisms in the water; and (*c*) the inorganic sediment. The transparency is found to vary within a given lake with the season, and with the position of the station. It is greater in winter than in summer, and increases with increasing distance from the debouchures of streams. The water of the blue lakes is

most transparent, that of the green less, and that of the yellow least.

IX. *Matter dissolved in the water of the lakes.*—With the exception of the salt lakes, none of the lacustrine waters contain so much as one gram of solid matter per liter, and in five cases only does it exceed .3 gram per liter. There are notable variations in the amount and kind of dissolved matter depending upon the character of the basin, and there are notable variations in the same lake in different seasons, and in different parts during the same season. In the summer the warm waters in the upper portions of the lakes are poorer than the colder waters below, in some of the dissolved substances, especially $Ca\ CO_3$ and SiO_2, while in winter the solutions are nearly uniform throughout. In general, the lake waters have less solid matter in solution than the inflowing rivers, showing that dissolved matter is lost in the lakes. This loss is attributed largely to precipitation, and it seems to be implied that calcareous tufa is of very common occurrence. This would hardly hold for the greater number of the lakes in the United States. With reference to dissolved gases, the conclusion is reached that the amount of these gases, chiefly CO_2, O, and N, are independent of pressure, but that they increase with depth on account of the lower temperature. The amount of carbonic acid gas dissolved far exceeds that of oxygen and nitrogen together, whether measured by weight or by volume. Little account is taken of other gases.

X. *Geological position and origin.*—The classification of lakes in general is briefly outlined, and the lakes of France fitted to the classification. Two primary classes of lake basins are recognized: (1) Those produced by barriers of one sort and another, and (2) rock basins. Of the barrier basins there are many types, most of which are represented in France. The barriers are of various types as follows: (1) *Landslides.* Lake basins produced in this way are found in the Alps, the Juras and the Pyrenees, but are not numerous. (2) *Ice.* No existing lake in France owes its existence to an ice barrier. One extinct lake is so classed. (3) *Moraines.* The moraine of an existing glacier is the barrier which gives origin to a single lake,—Lac Long in the Alps. Lakes which owe their origin to moraines of extinct glaciers are numerous and of several classes. Here belong (*a*) lakes in valleys which were occupied by glaciers, the moraine forming a dam at the lower end of the lake. Of this class there are several representatives in the Alps,

the Juras, and the Vosges Mountains, one in the central plateau, and one in the Pyrenees; (*b*) lakes which result from the blocking of a lateral valley by the moraine of the glacier which occupied the main valley. Of this there are representatives in the Alps, the Juras, and the Pyrenees; (*c*) lakes which lie in basins occasioned by the irregular deposition of drift. But two lakes fall into this category, one in the Alps, about which there is some question, and one in the Juras. In our own country lakes of this class are more numerous than any other. (4) *Lava.* Several lakes, the basins of which are formed by lava dams, are found in the central plateau. (5) *Volcanoes.* Two lakes in the central plateau owe their origin to growth of volcanoes in the bottoms of valleys. (6) *Craters.* Several lakes in the central plateau occupy craters. (It is not altogether clear why crater lakes should be classified among the lakes produced by barriers). (7) *River alluvium.* Lakes formed along rivers by the deposition of alluvium are represented by a few lakes in the Alps, Juras and along the Mediterranean coast. (8) *Bars.* A few lakes on the coast owe their origin to the construction of bars which shut off a portion of the sea water, leaving inland basins. (9) *Dunes.* There are several lake basins completed by dune barriers along the Atlantic coast.

Of the lakes which occupy basins in the rock, one group owes its origin to internal forces. In this category belong the basins produced (1) by violent volcanic disturbances, such as explosions, of which there are several examples in the central plateau; and (2) lakes produced by secular movements. To this class belong several lakes in the Alps (Geneva and d'Annecy), and in the Juras, though concerning the origin of the latter there seems to be some question. Of the lake basins originating through the action of external forces, there are (*a*) those resulting from solution effected by underground waters, represented in the Alps and along the Atlantic coast, in the Juras, along the Mediterranean, and in one or two other places; (*b*) lakes due to erosion of rock along fissures, as where a fissure crosses a watercourse; and (*c*) basins due to excessive local erosion by the ice, represented in the Alps by several examples, in the Juras by one possible example, in the Vosges by one, in the central plateau by several, and in the Pyrenees by a considerable number. Here belongs Lac Bleu, of extraordinary depth. It is probable that in the production of many of the lake basins more than one factor has been involved.

XI. *The life history of lakes.*—After a consideration of the various causes which may bring the life of a lake to an end, the history of a few of the principal lakes of France is sketched. The level of Lake Geneva has been lowered about 30 meters since the glacial time. It had one stationary level between the highest and the present levels, when the water stood 10 meters higher than now. The other lakes especially considered are Bourget, which has also been lowered in post-glacial time, and d'Annecy, which was formerly 15 meters lower than now. The rise was occasioned by alluvial deposits in the valley of the Fier, to which the outlet of the lake flows. These deposits have dammed the exit. The history of Lacs de Saint Point and Remoray —in the Juras—is also outlined, the interesting point being that they were formerly one lake, now divided into two by the growth of a delta completely across the narrow basin. The growth of deltas seems to have played a large part in the history of many of the mountain lakes. This is the natural course of events where torrential streams debouche into the standing water. Many other lakes appear to have had their areas greatly diminished by similar processes. Reference is also made to certain extinct lakes, and the criteria by which their former existence is recognized are briefly given.

The figures in the text of the volume are largely half tones, which unfortunately, cannot be said to be of more than medium grade. It could have been wished also that the few maps of the text which show features other than the topography of the lake bottoms, could have been clearer. On the whole they have so much ink, that it is difficult to find the points sought. It is always a serious problem to make a map clear, and at the same time get a great deal on it, and in this case the difficulty has not been overcome.

R. D. S.

On the Building and Ornamental Stones of Wisconsin. By. E. R. Buckley, Ph.D., Madison, Wis., 1898. Pp. xxvi + 544. Bull. No. 4. Economic Series No. 2 of the Wisconsin Geological and Natural History Survey.

Dr. Buckley's report is one of the most compendious volumes on the subject of building stones published in recent years. Of the three parts into which the subject-matter is divided the first treats of the demands, uses, and properties of building and ornamental stones in general. This is a valuable though brief discussion of the subject.

Part II, which forms the bulk of the volume, begins with a chapter on the geological history of the state, followed by a detailed description of the different quarry-areas. The igneous and metamorphic rocks are first enumerated and described, and the author clearly shows the variety as well as the architectural beauty and value of the granitic rocks of the state. The only metamorphic rock mentioned is quartzite.

The sandstones are divided into three classes, partly on a geographical and partly on a geological basis. The first class includes the northern Potsdam sandstone, comprising what is ordinarily known as the Lake Superior brownstone, which apparently differs quite markedly from the sandstones of the southern Potsdam area and the St. Peter's formation included in the second and third classes. Neat sketch maps show the location of the quarries with reference to the markets and the transportation facilities. The limestone quarries are conveniently divided on a geological basis into (1) the Lower Magnesian, (2) the Trenton, and (3) the Niagara.

Chap. VII relates to the areas from which suitable stone for different uses may be obtained, such as building stone, bridge stone, paving blocks, etc. It has a direct economic bearing that will no doubt be appreciated by architects, builders and dealers in stone.

In the next chapter there is a discussion of the results of physical tests which are conveniently summarized at the end of the chapter in a series of thirteen tables. The crushing strength may really have little significance to the scientist, but has great weight with the architect. In this respect the Wisconsin granites and limestones have shown surprising results. The excess of strength of the Wisconsin granite over that from other states is possibly not so great, however, as the tests might lead one to believe. Granting that Gilmore's formula is incorrect, it is not conclusive proof that a large cube is not stronger than a small one in a ratio greater than the comparative areas of the faces. It might have been better to have given the dimensions of the cubes of the granites tested from other states along with the figures quoted and permit the reader to draw his own conclusions.

One of the most important sections of the report has to do with the effects of freezing and thawing on the strength of building stones. Numerous experiments have been made leading to the conclusion that freezing and thawing, continued for a considerable period, lessen the strength of rock, and that the loss in strength is in a general way proportional to the crushing strength of the rock. In other words, the

loss of crushing strength is greater in rocks in which the porosity is low and the size of the pores small, than in rocks in which the pore space is high and the pores large. This conclusion is diametrically opposed to that which is popularly current. The explanation of this unexpected result is that in the case of rocks where the pores are large the included water is given off with sufficient rapidity to avoid the evils of freezing, while in the case of close-textured rocks which are saturated when frozen, the water does not escape, and the injury to the rock is greater. This is a point of great practical value, as well as of theoretical interest. The results of the experiments are given in detail in tabulated form. Part II also contains a set of tables in which are given the results of the various other physical tests to which the building stones of Wisconsin have been subjected.

Part III is an appendix in which composition, kinds of stone, and rock structures are discussed.

The form of the report is a convenient one, the binding is neat and attractive, the illustrations are numerous and for the most part well chosen. A carefully prepared map of the state is folded in the text. An attractive feature is the representation of the stones in their natural colors. No verbal description could arrest the attention so effectually or give the reader so vivid an idea of the beauty of the stone, as these artistic plates. If the printer is not at fault, however, one might wonder why the beautifully colored granite on Plate XII should be called gray.

The person who can write a perfect report on building stones has not yet attempted it. In Dr. Buckley's report there are some points which some of his readers might wish to change. Some are matters of personal taste and all are of somewhat minor importance compared with the much valuable matter forming the body of the report. Petrographers may not all agree entirely with the distinction between gabbro and diabase (p. 447). Some of the readers may not agree with the relative importance placed upon the different cements in sandstone given on p. 450, or with the conclusions about the use of quartzite on p. 455. All those who might agree with the author that "the joints in igneous rocks are more numerous than in the sedimentary" might not agree with him that it is "owing to the greater length of time through which they have been subject to dynamic action" (p. 459).

The report represents a vast amount of careful and conscientious work on the part of Dr. Buckley and will no doubt prove a valuable

handbook in the stone trade of Wisconsin. While it is prepared primarily in the interests of the stone industry of Wisconsin, it has much of general interest to persons outside of the state, and both Dr. Buckley and the director of the Wisconsin Geological and Natural History Survey are to be congratulated on presenting to the public such an interesting, attractive and valuable contribution on the subject of building stones.

T. C. H.

Irrigation and Drainage. Principles and Practice of their Cultural Phases. By. F. H. KING. The Rural Science Series. The Macmillan Company, pp. 502, 8vo. 1899. Amply illustrated.

In this work there is brought together a vast amount of experimental and experiental data relative to the physics of soils and their relations to water and air. These data are given in both their analytical form in the shape of tables, diagrams, and other modes of scientific expression, and in their concrete industrial form as exemplified in growing crops and in drainage and irrigation appliances. The treatment is very clear and specific and at the same time very compact. It is a conspicuous example of *multum in parvo*, if 500 close-set pages do not make the expression inapplicable. The author has personally studied the irrigation systems of Europe as well as those of this country, and has himself conducted careful experiments bearing on the fundamental principles involved. While thoroughly practical in its bearing, the treatment is firmly controlled by the scientific spirit. It is an admirable blending of good science and good technology.

T. C. C.

The Coos Bay Coal Field, Oregon. By JOSEPH SILAS DILLER. Extract from the Nineteenth Annual Report of the U. S. Geol. Survey, 1897–8, Part III, Economic Geology.

This paper deals almost wholly with economic interests of a very local character; and yet it is not without some facts of general interest. It is a description of a coal field of very limited extent situated on the coast of Oregon 200 miles south of the Columbia River. The coal is of Eocene age. Fossils of fresh and brackish water type are found in

immediate connection with the coal, while marine shells are found in the sediments separating the beds.

The seams contain true coal and "pitch coal." The true coal is of good quality, containing little ash. Much of it is "fat," containing as high as 66 per cent. of volatile matter. The "pitch coal" is found in veins and irregular masses in or near the true coal. The latter part of the paper is devoted to a discussion of the "pitch coal" by William C. Day, who concludes that it is an *asphalt*, as it shows none of the characteristics of coal.

W. T. Lee.

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THE

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THE NOMENCLATURE OF FELDSPATHIC GRANOLITES.[1]

MOST petrographers agree that the classification of granular rocks, if not of lavas, should be based on mineral composition. This resolves itself practically into the molecular composition. When we state that a rock is composed of quartz, mica, and orthoclase in certain definite proportions, we state the relative proportions of the molecules of which these minerals are composed, and this is true of all other minerals which are made up of a single molecule. But when we introduce terms such as plagioclase, which is composed of two molecules in ever varying proportions, we no longer treat of molecules as such, but of mixtures of molecules. It seems quite clear that the molecular method should be applied throughout, when practicable, and in calculating the composition of the feldspathic rocks the plagioclase should be resolved into the constituent albite[2] and anorthite molecules, and the term *plagioclase* should not be used. This is particularly necessary with monzonites and diorites, for it is clear that if we define typical monzonite as a rock composed of equal quantities of orthoclase and soda-lime feldspar, we may

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] We may treat the soda of the feldspars all as in albite, although some of it may be in the orthoclase.

have orthoclase with basic labradorite, although that must be rare, or, orthoclase with acid oligoclase. The nature of these two rocks would be so different as certainly to make us hesitate to designate them by the same name. In the feldspathic rocks it seems to me proper to base the classification of these rocks primarily on the feldspars, and if we subdivide the feldspathic rocks on the basis of the ratio of the alkali-feldspar molecules (Or + Ab) to the lime-feldspar molecules (An), the true mineral and, to some extent, the chemical relations of the rocks will be brought out, and I think more correctly classify them than to put the orthoclase, or the alkali-feldspars in apposition to the albite and anorthite molecules combined. In order to graphically represent the position of the various rocks under discussion there is now introduced a table which is self-explanatory. In the column represented in the table we have at one end of the series an alkali-feldspar molecule and at the other end a lime-feldspar molecule, and the feldspars of rocks may be said to be composed of one of these molecules or of isomorphous mixtures of the same. The rocks at the head of the column containing feldspars composed chiefly of orthoclase and albite may be designated as orthosite (from the French term orthose = orthoclase) when orthoclase chiefly is present; as anorthosite,[3] when anorthoclase chiefly is present, and as albitite when albite chiefly is present. The rock at the foot of the column, whose feldspathic constituent is largely anorthite, may be designated anorthitite.

It is impracticable at the present time, and, for the purpose of this paper, unnecessary to consider the position in this column of all the feldspathic granolites; a sufficient number, however, are introduced to show the result of the method here proposed, as follows:

Albitite-porphyry or *soda-syenite-porphyry.* — No. 1521 Sierra Nevada. Turner. Seventeenth Ann. Rept. U. S. Geol. Surv., Part I, p. 727. Composed

[3] The use of this term will be at once objected to by petrographers since it has already been used for rocks composed largely of labradorite and more basic feldspars. It is a question, however, since the term in this sense is a misnomer, if it would not be well to drop it.

Group	Rock	Scale
	Orthosite or Albitite	100 % Or. + Ab
GRANITE AND SYENITE	Albitite No. 1521 S. N. Ratio 35 : 1	
	Aplite of Granodiorite. Ratio 7.8 : 1	90 %
QUARTZ-MONZONITE AND MONZONITE	Granodiorite No. 103. Ratio 4 : 1	80 %
	Monzonite from Monzoni 3.8 : 1	
	Butte Granite. Average : 3.7 : 1	
	Idaho Basin Granite : 2.9 : 1	
GRANODIORITE	Banatite. Average / Granitite from Barr-Andlau 2.5 : 1	
		70 %
QUARTZ-DIORITE AND DIORITE	Quartz-mica diorite No. 3 : 69 : 1.5 : 1	60 %
	Quartz-diorite. Average ; 1.4 : 1.	
?	Division line between Diorite and Gabbro	50 %
GABBRO SERIES	Amphibole gabbro No. 1970. Ratio 1 : 1.5	40 %
		30 %
		20 %
		10 %
	Anorthitite	0 % (100 % An)

Part II, which forms the bulk of the volume, begins with a chapter on the geological history of the state, followed by a detailed description of the different quarry-areas. The igneous and metamorphic rocks are first enumerated and described, and the author clearly shows the variety as well as the architectural beauty and value of the granitic rocks of the state. The only metamorphic rock mentioned is quartzite.

The sandstones are divided into three classes, partly on a geographical and partly on a geological basis. The first class includes the northern Potsdam sandstone, comprising what is ordinarily known as the Lake Superior brownstone, which apparently differs quite markedly from the sandstones of the southern Potsdam area and the St. Peter's formation included in the second and third classes. Neat sketch maps show the location of the quarries with reference to the markets and the transportation facilities. The limestone quarries are conveniently divided on a geological basis into (1) the Lower Magnesian, (2) the Trenton, and (3) the Niagara.

Chap. VII relates to the areas from which suitable stone for different uses may be obtained, such as building stone, bridge stone, paving blocks, etc. It has a direct economic bearing that will no doubt be appreciated by architects, builders and dealers in stone.

In the next chapter there is a discussion of the results of physical tests which are conveniently summarized at the end of the chapter in a series of thirteen tables. The crushing strength may really have little significance to the scientist, but has great weight with the architect. In this respect the Wisconsin granites and limestones have shown surprising results. The excess of strength of the Wisconsin granite over that from other states is possibly not so great, however, as the tests might lead one to believe. Granting that Gilmore's formula is incorrect, it is not conclusive proof that a large cube is not stronger than a small one in a ratio greater than the comparative areas of the faces. It might have been better to hav [illegible] the dimensions of the cu[illegible] the granites tested from other [illegible] with the figures qu[illegible] permit the reader to draw his [illegible]ions.

One of the most importa[illegible] the effects of freezing and tha[illegible] Numerous experiments have b[illegible] that freezing and thawing, contin[illegible] strength of rock, and that th[illegible] portional to the crushing st[illegible]

loss of crushing strength is greater in rocks in which the porosity is low and the size of the pores small than in rocks in which the pore space is high and the pores large. This conclusion is diametrically opposed to that which is popularly current. The explanation of this unexpected result is that in the case of rocks where the pores are large the included water is given off with sufficient rapidity to avoid the evils of freezing, while in the case of close-textured rocks which are saturated when frozen, the water does not escape, and the injury to the rock is greater. This is a point of great practical value, as well as of theoretical interest. The results of the experiments are given in detail in tabulated form. Part II also contains a set of tables in which are given the results of the various other physical tests to which the building stones of Wisconsin have been subjected.

Part III is an appendix in which composition, kinds of stone, and rock structures are discussed.

The form of the report is a convenient one, the binding is neat and attractive, the illustrations are numerous and for the most part well chosen. A carefully prepared map of the state is folded in the text. An attractive feature is the representation of the stones in their natural colors. No verbal description could arrest the attention so effectually or give the reader so vivid an idea of the beauty of the stone, as these artistic plates. If the printer is not at fault, however, one might wonder why the beautifully colored granite on Plate XII should be called gray.

The person who can write a perfect report on building stones has not yet attempted it. In Dr. Buckley's report there are some points which some of his readers might wish to change. Some are matters of personal taste and all are of somewhat minor importance compared with the much valuable matter formin[illegible]ody of the report. Petrographers may not all agree entire[illegible]stinction between gabbro and diabase (p. 447). Some o[illegible]y not agree with the relative importance placed up[illegible]ements in sand stone given on p. [illegible] with the c[illegible]he use of quar[illegible] on p. 455. All [illegible] might [illegible]or that "the [illegible] in igneous [illegible] num[illegible] sedimentary [illegible] not agree [illegible] [illegible]ater length [illegible] through [illegible] action" (p. [illegible]

Th[illegible]eful and consc[illegible] work[illegible] doubt prove a [illegible]

at a great number of points in the granodiorite areas of the Sierra Nevada. Ratio, 1.5 : 1. Composed of albite> anorthite> quartz> orthoclase><biotite, amphibole, etc. Calculation approximate.

Quartz-diorite.—Turner. Average of five analyses of quartz-diorite from the Sierra Nevada. JOUR. GEOL., Vol. VII, 1899, p. 149. Ratio, 1.4 : 1. Composed of anorthite> albite> quartz> = orthoclase. In most of the quartz-diorites there are biotite, hornblende, and accessory minerals present. Calculation approximate.

Amphibole-gabbro.—No. 1970 Sierra Nevada. Turner. Am. Jour. Sci. Vol. VII, 1899, p. 297. Ratio, 1 · 1.5. Composed of amphibole> anorthite> albite> orthoclase. There are also present magnetite, pyrite, and pyrrhotite. Calculation approximate.

Taking the monozite from Monzoni as a typical mozonite with a ratio of $(Or + Ab)_{3.8} : An_1$ it is clear that if we accept the method here proposed the granodiorite No. 103, the Butte granite, and the Idaho Basin granite are properly quartz-monzonites. If we likewise place the banatites with quartz-monzonites, then the granitite from Barr-Andlau, and many of the granodiorites of the Sierra Nevada will likewise be quartz-monzonites.

The use of mineralogical terms in naming granolites of simple composition seems to me very desirable, although it is not practicable with rocks of complex composition. This can be done with most feldspathic types as follows:

Orthosite	composed	chiefly	of orthoclase
Anorthosite	"	"	" anorthoclase
Albitite	"	"	" albite
Oligosite	"	"	" oligoclase
Andesinite	"	"	" andesine
Labradite	"	"	" labradorite
Anorthitite	"	"	" anorthite

By the addition of abundant and essential quartz to the above ingredients we have appropriate names for the quartz-granolites as follows: quartz-orthosite or granite in its restricted use, quartz-andesinite, quartz-labradite, etc. In all the above cases the quartz is an essential and not an accessory ingredient. When accessory constituents are used in naming rocks the word

should, it seems to me, have the adjective form, as *quartziferous syenite* for a syenite containing some quartz. If such a scheme came into general use the term *granite* would still be a useful one for nearly all quartz-feldspar rocks, in which sense it is used by Michel Lévy and by many other geologists.

H. W. TURNER.

THE GEOLOGY OF THE WHITE SANDS OF NEW MEXICO

EAST of the San Andreas and Organ mountains of New Mexico is an extensive valley that has been the subject of much discussion from the practical as well as the theoretical point of view. The writer is not aware that any competent geologist has had the opportunity to make an exhaustive study of its unique features and ventures to put on record the results of a somewhat careful if cursory examination of the valley and its environs.

Our first visit was made by wagon from Socorro, the seat of the county of the same name, by a route which afforded ample opportunity to observe the varied geological conditions of the region to the north and east. East of the Rio Grande, after leaving the immediate valley of the river, the Tertiary red marls are encountered, and lie in rather low terraces upon the foot of the greatly disturbed red beds of Permian and Triassic age. These beds are tilted and greatly faulted, leaving one in doubt as to the sequence at this point, especially as there are curious beds of fire clay and shale filled with a varied flora of carboniferous habit consisting of numerous species of Lepidodendrids as yet not worked out specifically.

The lower part of the Permian is composed of limestones and sandstones capped by anhydride and gypsum beds, the former being in some places massive and upwards of fifty feet thick. Extensive exposures of what is apparently carboniferous limestone constitute the principal axis of the low range at this point, and are followed by the red beds over a large area on the eastern side. These beds, as everywhere in the territory, are impregnated with salt and saline alkalis as well as gypsum. The springs are nearly always salty, and lower flats are covered with "alkali." Passing southward, in the immediate valley of the Rio Grande, near San Antonio, is the remarkable basin of

so-called tripoli described by the writer some years since. There is no reason to alter the opinion then expressed that this fine-grained scale-like deposit is the result of the attrition of the floating pumice which forms the surface of the deposit. In fact, in several other places in the Rio Grande valley similar beds on a smaller scale have been encountered, and in each case the material could be traced directly to the acid scoria of the period of trachite eruption.

To the southeast we pass to the celebrated Carthage coal belt, at which point a collection of Cretaceous fossils was made, but, as they were not found in immediate connection with the coal beds, it is impossible to decide what is the age of the coal upon that basis alone. However, a little farther south in the vicinity of Engle and East of the Caballo Mountains fossils of the Laramie age seem to prove that the coal fields at this point are of that period.

At San Marcial and at frequent intervals down the valley are basaltic cones which have broken through the Tertiary gravels and marls and supplied the material for the sheets of lava so characteristic of the entire territory. It is easy to see that they follow in a general way axes of weakness extending north and south, but it is not so easy to determine the reason for a sudden return to highly basic conditions after a gradual increase in acidity in the volcanic flows of the territory. As the writer has shown in several papers, the sequence is from an augite-andesite or diabase through trachite and pitchstone and obsidian to rhyolite. The soda-syenite and phonolite may perhaps form a transition from the andesite, though the occurrence of the soda series is less general

It suggests itself to the writer that the serial arrangement is to be attributed to an invasion of the silicious crust by the internal heat, and that progressively less of the deeper material was involved in these flows until it may be said that that chapter of igneous activity was closed by the rhyolite eruptions. Long after, perhaps as a result of the differential strain of glaciation and its attendant shifting of the axes of rigidity of the crust,

deep crevices were formed entirely through the acid crust and permitted a slow and relatively quiet overflow. This method of eruption would account for a considerable degree of fluidity of the lava and for the very slight surface disturbance. However this may be, the flows of lava, usually of slight thickness, are often of enormous extent, and where water has had access to the loose materials beneath, the characteristic *mal pais* results.

Our way is now across the Jornado del Muerto, the perils of passage being greatly reduced by the sinking of wells for ranches at various places, though the terrors of a blizzard on these barren treeless plains needs but to be experienced to be appreciated. Though comparatively arid and seemingly barren, the short grass furnishes a good subsistence to many herds of both cattle and horses.

Rising by a rather moderate slope from the plain are the foothills of the great range which begins with the Sandias east of Albuquerque and is continued in a broken line by the Manzanos, the Oscuros, the San Andreas, and the Organs. In the Sandias and Manzanos the granite, everywhere lying at the base of the stratified rocks, so far as known, in the territory, is exposed in an extensive escarpment on the east side of a very important fault line and the superincumbent stratified rocks dip rapidly to the east. In both the ranges mentioned the rock lying upon the granite, or its gneissic or schistose equivalent, is a quartzite whose materials seem not to have been derived from the subjacent granite, but from a schist or quartz rock which we suppose to have been the superficial portion of that series. The age of the quartzite, as well as that of the granite, must at present remain a matter of conjecture in spite of poorly preserved fossils in the limestone layers found in one or two instances in the midst of the granite. Reposing on the quartzite conformably in the Sandia and Manzano ranges is a silicious series with a few limestone bands whose fossils seem to be of undoubted Coal Measure age. This is followed by a dark conchoidal limestone with shales having a fauna similar to that of the Upper Coal Measures in Ohio as will be more particularly set forth in another

place. The lower series we have called the Sandia series from the place where best seen. Some distance above the dark lime is a sandstone or conglomerate which is rather inconstant in thickness and may be absent, but which roughly marks the transition to the permo-carboniferous as generally developed in all the ranges under consideration. This Coyote sandstone is particularly well seen in the canyon of that name in the south end of the Sandias. Above this is the large series of massive gray and silicious lime at whose base it is usual to find a large form of Fusulina and, a little higher up, a well defined zone characterized by the bryozoa preserved on the faces of the cleavage slabs. Here begin the evidences of a transition to the Permian as indicated by the presence of *Mekella striatocostata*, *Terebratula bovidens*, *Productus punctatus*, and a variety of forms which are mingled with fossils also found in the carboniferous below. At the top of the gray lime is a large series of coarse, red quartzites and sandstones interbedded with dark earthy limestones and shales. There are few fossils except petrified wood and the few found still preserve a carboniferous habitus. This Manzano series is everywhere in evidence where a sufficiently high horizon is reached but is often removed from the crests of the range while it occurs in the eastern faulted extension. Following this is the group of red quartzites, sandstones, shales, and marls which we have recognized as the equivalent of the "red series" of Texas and Kansas. Three divisions can be made out in all parts of the territory examined which have been named from their prevailing or characteristic color, though it is not to be supposed that the color mentioned is constant. The lower or "red bed" division still retains some bands of limestone or lime breccias, the latter being a very characteristic element. Some 500 feet may be estimated as the average thickness of this division and prior to the work recently done in the valley of the white sands we had no definite evidence as to the age of the entire division. We only knew that a narrow bed of quartzite near the base at a point east of the Sandia Mountains contained the well-known Permian forms such as *Bakvellia parva*, *Myalina attenuata*, *Pleurophorus*

subcuneatus, etc. The major portion of the series proved obstinately barren. At the top of this division there are found in the most widely distant parts of the territory enormous deposits of gypsum and salt. In fact the presence of salines may be said to characterize the series, but especially at the passage from the red into the chocolate beds above it. The chocolate series has a thickness of at least 600 feet and passes through quartzites and gray and red sandstone layers into the loose vermilion marls and clays of the upper division. So far, we have no positive evidence as to the age of the two upper divisions, but may presume the chocolate beds to be Triassic and the vermilion division to represent whatever of Jurassic time is accounted for in the territory or at least in the central portion.[1]

South of the Manzano range the continuity of the uplift is broken so that in the Fra Cristobal and Caballo mountains near the Rio Grande and in the Oscuro range farther east the dip is, as in the Sandias and Manzanos, to the east while in the San Andreas, occupying an intermediate position farther south, the dip is to the west so that the high escarpment with its granite and schistose base faces the great salt plain.

In the interval between the range bordering the river and the Oscuro Mountains we have abundant evidence of the existence of the Cretaceous with its lignitic coals and it may be assumed that the Cretaceous also extends southward on the west side of the San Andreas, though nowhere exposed in the *Jornardo del Muerto*. Passing eastward lower horizons gradually emerge till, as we enter the interval between the north end of the Andreas and the south end of the Oscuros, the red beds are seen in the form of low hills with a dip to the east at the western foot of the Oscuros. Underneath is a part of the Permo-carboniferous. It appears, therefore, that the Oscuro range is separated by a fault line from the axis of the Andreas. On the west side of the San Andreas the red beds are represented as is shown by the extensive deposits of calcium anhydride in the foothills.

[1] It will be remembered that Professor Cope in 1875 identified part of this series as Triassic and that Dr. Newberry described Triassic plants from New Mexico.

The eastern escarpment of the Andreas is bold and irregular in the extreme but the fault which created it seems to have been wavy so that a crenulated or sinuous aspect is presented to the plain. The granite in some instances seems to have escaped in pinnacled or columnar form and throws off the restraining influence of the stratified rock to appear in jagged peaks. This is particularly true in the Organ Mountains where, however, there must be added the influence of a later trachytic overflow. Our examination of the San Andreas was cursory but was sufficient to show that the thickness of the stratified series is greater than in the Sandias and Manzanos. The lower portion is composed of quartzites and silicious shales which may be compared with the quartzites in the Manzanos. Above this is a large series of gray cherty limestones and quartzites of an entirely different texture and appearance. This has baffled our search for fossils in the Andreas and the Caballos where it is also well developed but, fortunately, we have been able to discover in the upper part of this series on the eastern side of the salt plain fossiliferous bands which place the age beyond doubt. Spirifer Grimesi, Leptaena rhomboidalis and other well-known Burlington brachiopods are associated with crinoids of that period in great abundance. Some of the bands are practically composed of the débris of the crinoids.

Above the Burlington there seems to be a hiatus, for the next species encountered are distinctively Coal Measure forms and the sequence from this on to the top is as in the ranges farther north though there seems to be a tendency for the limestone to encroach on the sandy elements and for the individual components to thicken toward the south, a fact which we interpret as indicating deep-sea conditions.

Attention has elsewhere been called to the method of occurrence of the copper found so widely scattered through these ranges. It was shown that the deposits of copper which have attracted so much attention were formed in veins that extend from top to bottom of the sedimentary series but do not seem to cut the granite, at least to any depth or with any regularity.

These veins are so regular that it is conceived that they may be best explained as the result of warping or shrinking in the sedimentary series and it seems certain that they have been filled from above. The vein matter is chiefly calcite, fluor spar, siderite and barite and it is chiefly at the intersection of the vein with a band of iron-filled quartzite, reposing on the granite and forming a definite selvedge to the sedimentary series, that the copper is deposited. The ores include nearly all the common copper compounds, calchocite, malachite, azurite, bournite and cuprite predominating. Here, as in Hannover and Santa Rita, it seems indubitable that the iron, accumulated by leaching, has been the agent in precipitating the copper.

Between the Organ and San Andreas mountains there is an area on either side where the granite is laid bare and it is true that some show of copper may be found in crevices and basins superficially on the granite. It is probable that all, or a great part, of the copper of the two ranges has been originally derived from the red-bed series (Permian and Triassic) by infiltration, for the original existence of the cupriferous series on top of the strata now remaining in the ranges is indubitable. Dikes of diorite cutting through the granite and sedimentaries along or near the fault line have caused portions of the latter to lie in irregular fragments along the foot of the escarpment to the east, the strata dipping towards the dike which served to pry them from their original position.

Standing upon a jutting eminence of the San Andreas and turning eastward one looks out upon a scene difficult to parallel. At one's feet is an enormous plain, apparently as level as a floor, over forty miles wide and extending as far as eye can reach to north and south. On the southern horizon rise the Jarillas Mountains which only partially interrupt the plain, while to the northeast are the snow-capped peaks of the Sierra Blanca. Northward the plain is narrowed by the eastward intrusion of the Oscuro range while it is possible to make out the dark area of basalt which covers that part of the plain to the east and southeast of that range. This is the widely-know "*mal pais*" of

Socorro county which has proven such an effectual barrier to communication between the Rio Grande valley and the growing region of White Oaks. South of the *mal pais* is a great white sea on which one can fancy the glint of white-caps. Such a body of water being out of the question the uninstructed observer would surely think himself the victim of a mirage but we recognize in the snowy area the famous white sands. Curious and conflicting stories are current respecting the area but the truth is not less interesting. We had already been forced to the conclusion that the true origin of the saline and gypsum beds is to be sought in the red series above mentioned. It seemed at first, however, that the geological relations would prove baffling.

Rising abruptly from the level plain on its eastern side are the foothills of the Sacramento range near which pass the trains upon the newly-finished El Paso and Northeastern railway. The escarpment is nearly perpendicular and the dip is very slight and to the east. The bottom of the sedimentary series is not reached, at least in this vicinity, but it is evident from a comparison of this with the western escarpment that the base is not far distant. The section is given in detail below but we were very fortunate in coming upon a locality where the lower portion of the section is fossiliferous About 560 feet from the base, at Dog Canyon, some 12 miles southeast of Alamogordo is a band of crinoidal limestone which, together with the gray lime and quartzite above it, contains numerous, though poorly preserved fossils. Among these enough forms were identified to determine the limestone as Burlington. As nearly as we could determine the Burlington is represented by at least 250 feet. Several intercallary sheets of igneous rock (diorite, with porphyritic hornblende) penetrate the strata and obviously connect with a boss farther east and higher up the canyon. The influence of the intrusive may account for the amount of chert seggregated in this portion of the section but, for whatever cause, the limes are chiefly highly silicious and quartzite has replaced former limestones. Above the Burlington, which is entirely absent farther north, is the entire series of Coal Measure

limestone and sandstone as seen in the Sandia range except that the deeper sea conditions have expressed themselves in greater thickness of limestone. The fossils in the lower part are of mid-carboniferous types but pass somewhat gradually into the assemblage which we have characterized as Permo-carboniferous. *Meekela*, *Terebratula bovidens*, *Productus punctatus*, a large *Bellerophon* and many other familiar forms indicate an approach to the top. Above the measured escarpment but inaccessible to our reach is a series of what appear to be yellowish sandstones or quartzites which may confidently be referred to the Manzano series at the top of the Permo-carboniferous. Northward the dip rapidly veers to the northeast and thus the several horizons drop below the surface and bring still higher ones than those seen at Dog Canyon within reach. About 16 or 18 miles west of the main escarpment is a low ridge of hills which prove to consist of carboniferous limestone but bearing evidence on their western aspect of the fault which brought the plain down to a lower level. This ridge is most instructive in showing that the fault was not a single break but by steps or successive faults. Wells in the plain to the west all show the existence of the red beds both by the presence of salt (often strong brine), but also by the red color of the marl brought to the surface. North of the outlyer spoken of is a most interesting spring which has built up for itself, geyser-like, a mound of some thirty feet above the general level from which issues a quantity of warm and highly saline water which flows into a depression and, sinking from view, leaves a large salt and alkali flat. Other similar lakes are grouped in the neighborhood. The actual character of the deposit is generally masked by a calcareous marl of white or gray color which forms a crust over the entire plain and is highly charged with salts except at the immediate surface.

But passing northward and observing several other saline springs similar to the one described, the route carries us through the intensely modern "boom" town of Alamagordo with its great sawmills fed from the Sacramento Mountains by a spur railroad and the equally typical old Mexican town of Tularosa

where nearly every house is of adobe. The intense red color of the adobe awakened our curiosity and led us to the examination of the escarpment to the east and north. As we hoped, the dip had sufficed to bring to the general level strata which at Dog Canyon were out of reach and the lower third of the red series with its capping of gypsum and salines is at the foot of the section. The following is the section as casually examined during our visit — a section which will yield a large suite of interesting fossils of decided Permian facies, though well-known carboniferous forms extend throughout. Commencing at the bottom, we have first a poorly exposed series of silicious shales and thin-bedded limestones in which is a characteristic Permian assemblage including *Myalina permiana*, *Myalina attenuata*, *Pseudomonotis hawni*, *Aviculopecten occidentalis*, etc.

Then follow, as we ascend:

Reddish shales and loose sands	15 feet
Limestone	6 "
Greenish sandy shale	10 feet
Coarse conglomerate with pebbles of granite, etc.	5 to 10 "
Purple red sand with pebbles	20 to 25 "
Earthy limestone	2 "
Loose red sand	18 "
Coarse red conglomerate	4 to 5 "
Red sandstone	8 "
Loose red sand and shales	18 "
Conglomerate	4 "
Limestone	2 "
Greenish sand	12 "
Earthy lime shales and sand	5 "
Limestone and calcareous shale	6 "
Sandy shale and green sands	35 to 40 "
Well marked bench of gray lime	8 "
Red shale including a very irregular conglomerate	4 to 8 "
Thin bed of lime	1 foot
Green fissile shale	6 feet
(Gypsiferous marl, probably surface deposit)	00 "
Limestone and shale with numerous small fossils	6 to 8 "
Brown or red shale with numerous fossils	35 "
Sandstone	8 "

Shale	6 feet
Sandstone	6 (?) "
Limestone	1 foot
Green sandstone with calcareous band	20 feet
Calcareous zone	00 "
White sandstone	4 "
Shell limestone fossils	1 foot
Nodular marl	15 feet
Nodular limestone	2 "

Our ascent ended here but beyond appeared the gypsum beds reposing upon red and white marls as in the Nacimiento region and elsewhere. Still above and forming separate terraces are the chocolate and vermilion beds, and at the top of the section the lower Cretaceous. The creeks or arroyos which traverse the gypsiferous horizon come laden with salt which is deposited as a white coating upon their beds and banks.

Having satisfied ourselves both as to the age and the character of the deposits which underlie the great plain, we undertook a study of the plains themselves. At the southern end of the *mal pais* which forms the northern boundary of our field of work, numerous springs gush out from beneath the thin sheet of black basalt. These springs differ from those from the salt valley itself, in that the water is not warm nor appreciably salty. It is apparent that the lava has served to retain the water which, on making its way beneath the sheet, has excavated channels in which the water may be heard rushing by one crossing the lava. One of these streams in particular, at Mal Pais spring, forms a considerable creek which supports a varied plant and animal life including fish of considerable size and several crustaceans (Gammarus or the like). The water, before it flows many rods, becomes distinctly salty and bitter. At a little distance to the south begins an area of depression which is forty miles long and receives the drainage from all directions. This whole area is covered with saline efflorescence while all the shallows, when dry, as they are most of the year, have considerable deposits of salt on the surface and the subsoil or under clays are infiltrated with alkaline salts the nature of which will be fully discussed in another place

About one mile from the Mal Pais spring above mentioned is a small salt lake which has furnished the salt for ranches for a radius of many miles during the historic period and at our visit the surface was covered to the depth of an inch or so with pure crystalline chloride of sodium. Still west and forming the western limit of the visible saline beds, is a drainage arroyo whose source seems to be in the red beds that emerge west of the Oscuro Mountains and conveys their saline water to the basin of the sands. Along the course of this arroyo are numerous salinas and alkali flats and these gradually broaden to form what may be described as one vast alkali and salt plain where brine stands for part of the year. Other arroyos come in from the west in some of which, even at the time of our visit, was a considerable quantity of flowing water which is a strong brine unfit for cattle even when accustomed to drink from the saline springs which unwonted animals will reject. Where these arroyos enter the salt lake and along the shores of the lake are bluffs of erosion some of which are over twenty feet high. In these exposures we encounter the red bed formation with its marls and gypsum deposits. Large quantities of pure crystalline gypsum are here exposed and the marls are alkaline and saline. We have therefore local proof, as well as the most conclusive evidence from the environs, that the whole of the plain is in or near the horizon of gypsum and salt that separates the lower from the middle member of the red or saline series.

In the salt flats the ribs of gypsum rise in successive ridges, and the action of the elements soon breaks up the exposed crystals into small grains which are carried by the winds hither and yon. This characteristic of the salinas accounts for the most curious and notable of the many peculiarities of these plains, namely the white sands. These have been attributed to the action of springs and the material has been supposed to have crystallized from solution. It has been suggested that the sands have been collected by floods, but a short examination shows that these great drifts are simply sand dunes collected from the gypsum sand formed as above stated on the surfaces of the lakes. The salt

and alkaline salts are also driven with the gypsum but on account of their solubility they do not remain in the dunes. These dunes lie to the south and east of the flats whither they are driven by the prevailing winds and not only cover a large part of the salinas themselves, but form a growing fringe to the east and south. The dunes are, in the majority of instances, very pure gypsum though there is a small commingling of earthy impurities. The soil underneath is impregnated with salt and soda and salt lakes are scattered over the area covered by the dunes. The intervals between the crests of the ridges support a scanty but very interesting vegetation. Near the southeastern angle of the sands is a very important salt lake which has been known as a source of salt for the ranches for many years. The north and south extent of the "white sands" is about 35 miles while the greatest breadth at the southern margin is about 18 miles. The lines connecting the extreme points are irregular, enclosing roughly a triangle of about 350 square miles. To this may be added nearly as much more of saline land on the west and in isolated areas to the south. The whole plain is geologically of the same nature, but, inasmuch as it is either higher than the basin or is more completely drained (to the south), the saline ingredients are not brought to the surface.

East of the Jarillas Mountains this plain again gives external evidence of its subterranean supply of salines while far to the north, beyond the covering of lava, there are depressions of the same character and of the same geological age and nature. The fact that such depressions occur in New Mexico only in connection with the red beds leads to a suggestion that may be worthy of consideration. It is evident to anyone who has studied the geology and geography of the territory that it is, as Major Powell said long ago, the best drained region in the world. The comparative newness and permeableness of its strata all militate against the formation of local basins. There has been no glaciation to produce local lake reservoirs. Erosion has kept well in advance of secular changes of level and barriers of local origin do not prove capable of retaining the waters which come in

torrential plentitude when they come at all. Some explanation must be sought for the basins found in the saline areas. It might be supposed that such explanation would be found in the depressions resulting from the post-Tertiary lava flows which occur over the entire territory. To this it may be replied that the basalt is certainly of deep origin, for the preceding flows were all acid and the basalt overflows are essentially similar among themselves and demand a common origin at a depth. Moreover the distribution of the flows indicates that the orographic lines of weakness opened were of almost continental extent. The depressions due to the outflow of basalt would not account for the local basins referred to and we are driven to the conclusion that these slight depressions are due to the effect of the removal of the soluble ingredients in these beds themselves.

The discussion of the economic aspects of these beds will occur in the forthcoming bulletin of the University Geological Survey of New Mexico.

C. L. HERRICK.

DESCRIPTION OF PLATES

PLATE I.

Sketch map of the region of the "White Sands" including part of Dona Ana, Socorro, and Otero counties, New Mexico.

PLATE II.

Mostly Permian fossils from exposures near Tularosa and east of the Sandia Mountains in Bernalillo county. These plates are given to illustrate the fauna rather than as a basis for a discussion of the species figured, which have as yet been subjected to no critical study.

FIG. 1 *Pseudomonotis* n. sp. (*costatus*).
FIG. 2. *Bellerophon* sp.
FIG. 3. *Aviculopecten cf. coxanus.*
FIG. 4. *Pseudomonotis radialis* Meek.
FIG. 5. Undetermined.
FIG. 6. Undetermined.
FIGS. 7, 8. *Rhynchonella osagensis* Swallow. Two views.
FIG. 9. *Pleurotomaria cf. subdecussata* Geinitz.
FIG. 10. *Pleurotomaria marcouiana* Geinitz.
FIG. 11. *Rhynchonella* sp. Two views. (*cf. R. osagensis* Swallow).

FIG. 12. *Terebratula ?* sp. Two views.

FIG. 13. *Zaphrentis* sp.

FIG. 14. *Productus cora* D'Orb.

FIG. 15. Portion of the whorl of *Euomphalus* sp.? All the above are from shale number III of the Tularosa section.

FIG. 16. *Bakevellia parva* Meek and Hayden. From base of section near adobe smelter east of Sandia Mountains at the base of the Permian.

FIGS. 17, 18, 19. Undetermined gasteropods from the base of the Tularosa section.

FIG. 20. *Orthoceras* sp. Base of Tularosa section.

FIG. 20 *bis*. (Lower left corner) *Edmondia* sp. Same place as the above.

FIGS. 21, 22, 23. *Meekella striatocostata* Cox. From No. 3, Tularosa section.

FIG. 24. *Myalina permiana*, base of Tularosa section.

FIG. 25. *Bellerophon montfortianis* Norwood and Pratten. Base of section at adobe smelter.

FIGS. 26, 27. *Pleurophorus subcuneatus* Meek and Hayden. Same as the above.

FIG. 28. *Sedgwikia topekaensis* Shum. Shales below upper layers at Tularosa.

PLATE III.

FIG. 1. *Aviculopecten occidentalis* Shum. Left valve.

FIG. 2. *Aviculopecten occidentalis* Shum. Right valve.

FIG. 3. *Pseudomonotis hawni* Meek and Hayden. This and the above from the lowest level of the Tularosa section.

FIG. 4. *Myalina perattenuata* Meek and Hayden. Adobe smelter east of Sandias.

FIG. 5. *Myalina swallovi* Shum. Upper Carboniferous, Sandia Mountains.

FIG. 6. *Discina convexa* Shumard. As above.

FIG. 7. *Gervillia longa* Geinitz. As above.

FIG. 8. *Chonetes granulifera* Owen. As above.

FIGS. 9, 10. Unidentified gasteropod. As above.

FIG. 11. *Myalina ?* Permo-Carboniferous east side of Sandia Mountains.

FIG. 12. *Edmondia* sp. Base of Permian, adobe smelter.

FIG. 13. *Edmondia aspinwalensis* Meek. Permo-Carboniferous. Jemez Spring.

FIG. 14. Unidentified gasteropod. Upper Carboniferous.

Plate I


CRETACEOUS
SALINE PLAIN
Red Series
Saline Flat
Lava Bed
Oscuro Mts
LAVA
PERMIAN
Jane's Hill
Capitol Pk.
Salinas Pk.
CARBONIFEROUS
SAN ANDREAS MTS
Salt Plain
Red Series
Salt Creek
Salt Marsh
Dunes
Tularosa
Saline Flats
Sierra Blanca
La Luz
JORNADA DEL MUERTO
Salt and Alkali Flats
Gypsum Dunes and Saline Plain
Alamogordo
Salt L.
White Water Sp.
Salt Sp.
SAN ANDREAS MTS.
Red Series
Marls
San Nicholas Sp.
Fault
El Paso
E. P. & N. E. R. R.
Alluvial
Jarillas Mts.
Saline Plain
Dona Ana Mts.
TRACHYTE
Organ
Augustine Pass

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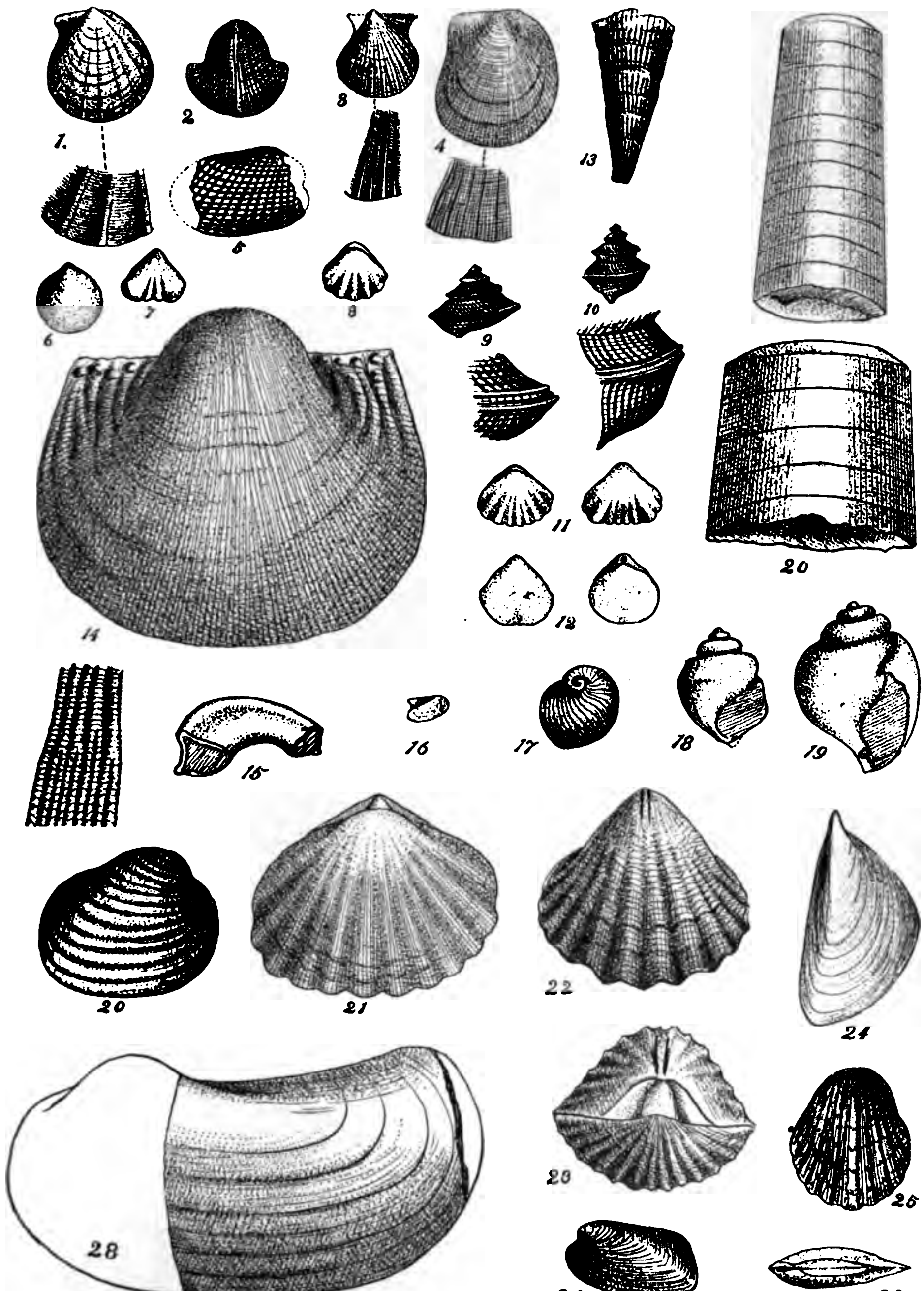
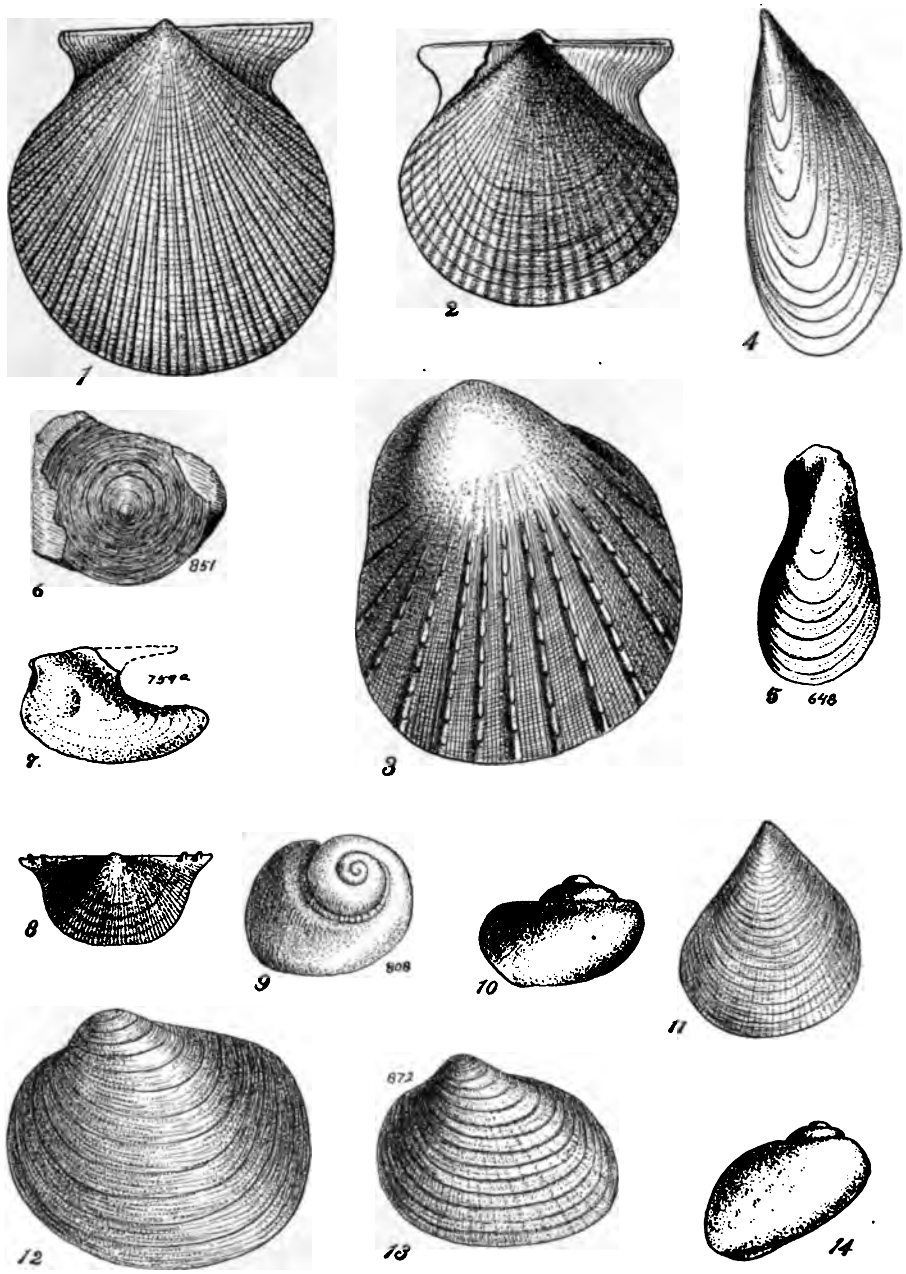
Plate II



Jour. Geol., Vol. VIII, No. 2 Plate III



THE ORIGIN OF NITRATES IN CAVERN EARTHS

MUCH interest has been taken in the great caverns of Virginia, Kentucky, and Indiana by tourists, and considerable popular literature has been published, especially in description of Mammoth, Luray, and Wyandot caves. In this literature rather frequent allusion is made to the "nitrates" in cavern earths; and occasionally a theory is advanced to explain their origin. Popular interest is awakened in this question by the large amount of "saltpeter" known to have been taken from Mammoth Cave during the war of 1812, and from similar caverns in Alabama and Georgia during the Civil War for the manufacture of gunpowder.

The origin of this supply of nitrates is commonly ascribed to animal remains, and especially to the excrement of bats. In Mammoth Cave, however, the cavern earth was worked for nitrate for a distance of over five miles from the only opening known which leads to the surface, while bats as a rule go but a short distance from the entrance of the cavern. Again, on account of the antiseptic character of the atmosphere of caves, we would expect, in case the nitrate was derived from bats, to find some animal remains, in the form of their dried bodies, their bones, or their excrement; but organic matter of any kind is rare in cavern earths. The hypothesis ascribing such an origin to the vast stores of nitrates taken from Mammoth and other caverns seems, therefore, inadequate.

Caves in limestone regions are due to the solvent action of water containing carbon dioxide. This process must have been very slow and in most cases unaided by mechanical erosion, thus leaving the insoluble portion of the limestone as a deposit on the floor of the cavern. This residue is known as cavern earth.

From the mode of formation of caves, it is evident that this residue must have been washed perfectly free from all salts

readily soluble in water by the water which slowly carried away the limestone itself during the formation of the cavern.

Recent progress in bacteriology and agricultural chemistry has thrown much light upon the origin of nitrates in soils by the oxidation of organic matter in the presence of certain bacteria. The surface soil in cavernous regions is usually loose and porous, and consequently favorable both for nitrification of organic nitrogen and for downward percolation of the surface water. It may not be unnatural, then, to ask whether the nitrates in cavern earths may not have orginated wholly or in part from nitrification of organic matter at the surface and the subsequent leaching of the nitrates so formed into the caverns. Caves would thereby act merely as receptacles for the surface drainage, and provide an avenue for the return of the percolating water to the atmosphere by evaporation. If the nitrates in caves originated in this way, we would expect to find also in cavern earths such other soluble constituents of soils as must necessarily have been leached out along with the nitrates.

By leaching cavern earths with cold water some material is always extracted. The amount thus washed out is sometimes as much as 13 per cent. of the sample. The following analyses are given of the soluble matter of cavern earths derived by washing the samples with cold water, the figures representing percentages :

Source	Calcium oxide	Sulphuric anhydride	Alkalis	Chlorine	Nitric acid	Ammonia
Mammoth Cave, Ky.	1.06	2.16	1.45	0.28	0.37	0.005
Mammoth Cave, Ky.	3.20	4.57	3.04	1.41	1.36	0.001
Saltpeter Cave, Ind.	2.31	3.30	2.26	0.23	1.88	0.007

From these results it is seem that nitrates form only a small portion of the total soluble material in cavern earths.

A kilo of subsoil over Mammoth Cave was placed in a percolator, and two liters of water charged with carbon-dioxide were added and allowed to stand for a week, with frequent stirrings, when the water was slowly drawn off. The water was then

evaporated in a platinum dish and the residue was analyzed. A sample of cave earth collected as nearly as possible beneath the spot where the sample of subsoil was taken, was also treated in the same way. A sample of bat guano and one of the earth occurring just below the guano were subjected to the same treatment. The results of these several analyses are given in the following table, the figures representing percentages of the sample taken:

	Mammoth Cave		Dixon's Cave	
	Subsoil over Mammoth Cave	Cave earth below	Bat guano	Earth below bat guano
Sulphuric acid, SO_3	0.0054	4.16	0.67	0.031
Lime, CaO	0.0018	2.03	3.34	0.23
Alkalis, Na_2O, and K_2O	0.00288	2.86	0.37	0.26
Phosphoric acid, P_2O_5	trace	0.0003	0.044	0.0137
Ammonia, NH_3	0.00192	0.011	0.102	0.019
Nitric acid, N_2O_5	0.0068	0.82	6.016	0.0118

By comparing these analyses it is evident that the soluble material in the cave earths might have been leached from the soil above.

The bat guano forms a thin layer over the floor of Dixon's Cave, and is composed of a mixture of excrement and fuzzy material from the bats' bodies, together with sand and earthy matter from the walls of the cavern. Judging from the above analyses, this layer seems to have acted as an excellent absorbent preventing the further percolation downward of material dissolved from the soil above the cave, since the earth below contains very little soluble material.

But guano was found to contain considerable amounts of salts of phosphoric acid soluble in cold water, while the cavern earths proper contain only traces of these salts. The total percentage of phosphate dissolved out of bat guano by dilute acid was found to be about the same as that derived from cave earth by the same treatment. The following results of analyses of bat guano, taken just as it came from the cave, making no attempt to mechanically separate the sand and earthy matters, and of cave

earth, both from Dixon's Cave, were obtained by igniting the dried samples and then treating them with dilute hydrochloric acid.

	Bat guano from Cave	Cave earth from Dixon's
Loss on ignition	32.16	6.02
Insoluble residue	40.65	73.80
Soluble silica, SiO_2	1.03	trace
Calcium oxide, CaO	10.95	7.51
Ferric oxide, Fe_2O_3	1.20	3.37
Alumina, Al_2O_3	5.27	2.41
Magnesia, MgO	0.37	0.30
Sulphuric anhydride, SO_3	4.37	2.77
Phosphoric anhydride, P_2O_5	2.62	2.10
Alkalis and loss	2.38	1.72

This sample of cave earth contained no perceptible organic matter.

It seems from a comparison of these analyses that we cannot prove the presence of animal remains by the total content of phosphoric acid soluble in dilute mineral acids, since a residue from limestone must contain considerable calcium phosphate on account of the insolubility in water of this salt of calcium.

Analyses of the water dripping from the roofs of caves were made, and results were obtained which do not vary markedly from results obtained from analyses of ordinary sub-drainage waters. The following is an analysis of the residue from water which dripped from the roof of Mammoth Cave:

Analysis of water dripping from the roof of Mammoth Cave

	Milligrams per liter
Silica, SiO_2	12.23
Sulphuric Anhydride, SO_3	15.81
Phosphoric Anhydride, P_2O_5	trace
Chlorine	2.71
Ferrous Carbonate, $FeCo_3$	1.02
Calcium Carbonate, $CaCO_3$	53.61
Magnesium Carbonate, $MgCO_3$	7.17
Alkalis, Na_2O and K_2O	16.56
Ammonia, NH_3	0.04
Nitric Acid Anhydride, N_2O_5	5.71

A comparison of the soluble constituents given in this analysis with the soluble material extracted from the cave earth, as

shown in the preceding analyses, points forcibly to the probable origin of these salts in cavern earths.

It was found from analyses of many samples taken from Saltpeter Cave, Indiana, so as to cover practically the whole floor of the cavern from the opening to the end, that nitrates were distributed throughout the entire extent of the dry chamber, irrespective of distance from the entrance. Since bats do not go far inward from the entrance of caves, and since we find no organic matter in cave earth to indicate an animal origin for the nitrate contained therein, it is evident that we cannot regard the nitrates in cavern earths as originating from bat guano.

The conclusion reached from this investigation is that the nitrates in caves were brought in by water percolating through the soils above the caves and were deposited on the floors. Currents of air in and out of the caverns removed the water, and the various salts it previously held in solution were left as an inheritance to the cave earth. A cavern acts, therefore, merely as a receptacle for stopping a portion of the surface drainage. This accumulation of salts occurs only in caverns where the inflow of surface water does not exceed in amount the water removed by evaporation. In wet caves the soluble salts are washed onward with the water bearing them and so are not deposited.

Nitrates found under overhanging cliffs are of a similar origin. Water bearing dissolved nitrates percolates through the soil and finally oozes out at the surface. The water evaporates and leaves behind an incrustation of its soluble materials. The nitrates thus formed under overhanging cliffs remained permanently stored there, being securely protected from rain. They served, along with the nitrates found in the caves of Alabama and Georgia, as a source of saltpeter used by the South during the Civil War for the manufacture of gunpowder.

When vegetable matter is piled up and allowed to deçay, an incrustation of potassium nitrate forms on the surface. The vegetable or organic nitrogen has been oxidized to nitric acid. The nitric acid combines with the potash of the plant to form potassium nitrate. The water evaporates from the pile and

leaves its load of nitrate behind as an incrustation on the surface, while water from the interior of the pile works gradually towards the surface to take the place of the water removed by evaporation. Thus the materials soluble in water are slowly brought to the surface and left as a deposit which may be removed mechanically. This is an old method of obtaining saltpeter from manure heaps, and it is even now used to a small extent in Europe. The occurrence of the nitrates in caves as an incrustation on the surface of the cavern earth shows that water has been removed by evaporation in much the same way as from the overhanging cliff and from the compost heap.

We always have nitrogenous matter scattered over the surface of the soil and this decaying vegetation furnishes continuously during its decay a small amount of nitric acid. All nitrates are soluble in water and so are sure to be found in the percolating water. If, then, the percolating water is intercepted and evaporated, the nitrate must be left behind. Nitrates should, therefore, occur in all caves and analyses of the cavern earths of a great number of caves in Indiana and Kentucky demonstrates that the occurrence of nitrates in cavern earths is general. No dry cavern earth was found which did not contain soluble salts of nitric acid, and these salts were distributed uniformly from the entrance to the end of the cavern.

WILLIAM H. HESS.

February 23, 1900.

THE CALCAREOUS CONCRETIONS OF KETTLE POINT, LAMBTON COUNTY, ONTARIO

It cannot be said that the mechanics of the concretionary process in sedimentary rocks is well understood. The well-known spherical concretions of Kettle Point, at the southern end of Lake Huron, appear to throw some light on the problem of the *mise en place* of thoroughly exotic material, aggregated by this slowly acting molecular attraction. The purpose of the present paper is to illustrate the mode of occurrence and to indicate some facts leading toward the interpretation of these singular bodies.

Logan has given us a concise description of the conditions at Kettle Point in the *Geology of Canada*, published in 1863.[1] Reference is also made to them by Rominger;[2] but in neither case was actual illustration employed nor description given of perhaps the most remarkable characteristic of the concretions.

About one half mile eastward of Kettle Point the highway from the town of Thedford decends sharply on a remarkably well preserved sea cliff of the formerly expanded Lake Huron, to the level of a gently sloping bench, cut in part in the drift, in part in the shales which underlie all this portion of Lambton county. At the Point itself the shales are seen to be wasting very rapidly on the face of a modern cliff from six to fourteen feet high and a few hundreds of yards in length. This condition is highly favorable to the exposure of the concretions, and one could hardly ask for more ideal sections for the study of structural details in the bed rock.

According to Logan these beds represent the equivalent of the Genesee Shale in New York state, which bears concretions of the same nature as those under consideration.[3] Rominger

[1] Pp. 387, 388.

[2] Rep. Geol. Sur. Michigan, Vol. III, 1873–1876, p. 67.

[3] Cf. HALL, Geology, Pt. IV, in the Nat. Hist. of New York, pp. 220 and 230.

put them in his "Black Shale" division of Michigan,[1] which C. E. Wright has called the "St. Clair Group."[2] The wide extent of these shales is further emphasized by their correlation with the important zone of the "Huron Shale" in Ohio.[3]

At the Ontario locality the rock is argillaceous throughout, of a dark brownish-gray to black color, which is partly due to

FIG. 1. General view of the shale at Kettle Point, showing jointing. Several concretions appear above the surface of the water.

the strong impregnation of bituminous matter, so abundant as to make the rock inflammable. Fossils are not rare; indeed, there is a very striking exhibition of large specimens of *Calamites inornatus*, and of other plants, lying prostrate in the shale. In addition to the calcareous concretions there is a great abundance of concretions of iron pyrites, which are, however, always small, generally lenticular, with the greatest diameter under three

[1] Op. cit., p. 67.

[2] Rep. Geol. Sur. Michigan, Vol. V, 1881–1893, Pt. II, p. 21 (ed. by Lane).

[3] NEWBERRY, Geology of Ohio, Vol. I, 1873, p. 154.

inches. The decomposition of the pyrites has led to the efflorescence of the usual sulphates of iron and alumina and of the hydrous oxalate of iron, humboldtite.

The shale is nearly horizontal, well laminated and very fissile, the flakes of the rock being readily split out and piled up on edge by the waves, which thus build a curious belt of jagged and

FIG. 2. Concretion and deformation of the shale.

shattered fragments on the bed rock. The only other notable structure in the interconcretionary spaces is the universal occurrence of two extremely perfect systems of vertical joints at right angles to each other (Fig. 1). These joints affect the shale only, and do not pass through the concretions anywhere, so far as I have had opportunity of observing the latter.

The most striking structure in the shales is, however, the local departure from the normal horizontal position of the parts of the beds in the immediate vicinity of the concretions. In every one of the dozen well-exposed concretions still in place the strata are plainly arched over the upper hemisphere and bend

under the lower, and show clearly the effect of deformation along the radii of the equator. In fact, the impression is at once given the observer that centrifugal force of nearly equal amount has been exerted along all radii of each sphere (Figs. 2, 3, and 5). A similar disturbance of the usual, nearly horizontal, attitude of the beds of this formation has been noted by New-

FIG. 3. Deformation of the shale about a medium-sized concretion.

berry at Worthington, Franklin county, Ohio,[1] and by Rominger in the "Black Shale" of Michigan.[2]

The concretions themselves are composed essentially of crystallized carbonate of lime, the crystals arranged radially and always in direct contact with one another. There is practically no argillaceous material in them, and in no observed case does the stratification of the country-rock run through the concretion. The shape is usually that of the almost perfect sphere (Fig. 4), though often this form is somewhat lost by the slight flattening

[1] Geology of Ohio, Vol. I, 1873, p. 155.

[2] Op. cit., p. 66.

of the concretion along the diameter perpendicular to the plane of stratification of the shale. True spheres and spheroids exhaust the list of observed forms. The average diameter is nearly two feet; the largest specimen now well exposed on the shore, a spheroid, has a polar diameter of a little more than three feet, an equatorial diameter of about three feet six inches

FIG. 4. General view of partially exposed concretions.

(Fig. 5); the smallest specimen may measure about one foot in diameter.

Large numbers of the concretions are being washed out of the much less resistant shales by the waves; their freeing from the matrix may be seen in all its stages (Fig. 4). But the number now remaining on the shore does not represent the total that could be counted were it not for the deplorable habit of the numerous visitors to the Point, who not only carry away the heavy specimens bodily, but break up others with the hope, destined to disappointment, of finding something at the core more

interesting than the interior of the already shattered "kettles." It is said that the concretions may be seen on the bottom in the very shallow water of the lake five or six miles from Kettle Point, and that specimens may be readily fished from the bottom as much as two miles from the shore, where they have been leached out by the erosive action of the larger waves.

FIG. 5. Large concretion in place; the shale in its immediate vicinity exhibits slaty cleavage developed tangentially to the concretion.

Composing as they do such a comparatively large proportion of the rock, and occurring in similar profusion in the Upper Devonian of Michigan and Ohio, it is hardly just to say, in the words of Dana, that radial spherical concretions are "of inferior geological importance.[1]

A chemical analysis of one of the darker tinted brown concretions was made, and yielded the following percentage com position:

[1] Manual of Geology, 4th ed., p. 97.

$CaCO_3$	88.42%
$MgCO_3$	2.99
Fe_2O_3	0.71
Residue insoluble in HCl (SiO_2)	4.25
Hydrocarbons (and H_2O)	3.23
	99.60

FIG. 6. Looking down on the concretion of Fig. 5; fractured surface shows concentric structure, the radial arrangement of the crystals not conspicuous in the photograph.

The powder from which this analysis was made was previously dried at ordinary temperatures in a desiccator; any residual water was driven off at the low heat used to expel the hydrocarbons. The latter cannot then be said to have been exactly determined, but they probably do not total less than 3 per cent. The shales round about were found by Hunt to contain 12.4 per cent. of volatile matter, presumably hydrocarbons.[1] The appearance of the magnesian carbonate is to be correlated with the

[1] Chemical and Geological Essays, p. 179.

observation by Garwood that some of this substance must be present if a limestone concretion is to grow large, although his analyses show that more than 30 per cent. of that carbonate seems to prevent the concretionary process.[1]

In all cases the structure is typically radial throughout the concretion, except at the rather indefinite small core of massive crystallized lime carbonate, which can usually be seen at the center. I have found no organic center of concretion, and no center other than calcite in any specimen. The free ends of the radiating crystals present the characteristic cleavage-planes of calcite, and the curved surface of the sphere is otherwise indented only by the faint depressions where the latter was in contact with the layers of shale (Fig. 5). Lastly, there is often to be seen, in addition to the radial structure, a concentric banding in the split-open sphere, a layering that seems to be original and connected with varying conditions of growth (Fig. 6).

The most important problem in connection with these concretions doubtless adheres to the question as to how the strata came to be deformed on all sides of each spheroid. That very considerable mechanical energy has been expended in the process is evident, not only in the development of a dome over the upper hemisphere and of a cup holding the lower hemisphere, but also in that of a sort of slaty cleavage, which can sometimes be discerned in the shale adjacent to the equatorial zone (Fig. 5). What is the source of the energy?

One of the first explanations that suggested themselves to me consisted in referring the deformation of the beds to differential movements in the strata as these adjusted themselves to the loss of water, and to the ensuing consolidation of the original muds to shale. The concretion itself would not lose bulk in such a case, and the layers overlying would be supported at the upper pole of the spheroid, while there would be less and less of such support for the same strata along lines radiating from the pole in the horizontal plane, until a maximum of instability would be reached outside of the equatorial circle. Here there would

[1] Geol. Mag., 1891, p. 439.

be a maximum of collapse which means, in the end, a doming above the upper hemisphere. I have found that the same explanation had been brought forward by both Newberry[1] and by Rominger.[2] But it leaves out of account the structural cup, which holds the lower hemisphere, and which is just as well developed as the dome overhead (Fig. 3). Moreover, the existence of the concretion before the act of consolidation is not considered; yet we must believe that a theory of the deformation should be controlled by the recognition of the fact that many cubic feet of the shale must be displaced to permit of the growth of the larger concretions.[3] We know of no reactions by which replacement of argillaceous material by slow molecular interchange with carbonate of lime may take place, nor can we conceive of such large spherical and spheroidal cavities as those necessary for the segregation of the calcite as having antedated the segregation. The last supposition is particularly invalid, for, in any case, it would leave the radial structure unexplained.

The same objection may be made to the hypothesis that energy sufficient for the deformation of the strata might be forthcoming in the process of forming a pseudomorph of calcite after some other carbonate of greater density. Siderite does, indeed, occur in radially concretionary form in the Black Shale of Michigan.[4] But, while there might be an important increase of volume with the application of expansive energy analogous to that ensuing on the change from anhydrite to gypsum, we have still to account for the original displacement of the shale to make way for the siderite or other earlier carbonate itself. It may also be stated that the disturbance of the shale is visibly greater than is possible on a mere change of volume in the pseudomorphosing reaction.

There thus seems to be no escape from the conclusion that the crystallization of each concretion and the opening of the

[1] Op. cit., p. 155. [2] Op. cit., p. 66.

[3] NEWBERRY'S largest concretion of the sort here described, and occurring under similar conditions, measures 10 feet in diameter, giving a volume of more than 500 cubic feet. Geology of Ohio, 1873, p. 155.

[4] Geol. Surv., Mich., Vol. III, 1873–1876, p. 67.

space in which it lies were contemporaneous processes ; the force used in deforming the beds must, in some way or other, be directly connected with the act of crystallization of the calcite.

The theory of this association that lies nearest to hand would explain it by deriving active mechanical energy from each crystal of calcite as it obtains new material at the outer extremity on the surface of the growing spheroid. This energy will, then, be that of a "live force," and will be directed centrifugally, forcing the shale to assume a position dependent on the relative rate of growth of the crystals in the bundle. If there be equal supply of carbonate in the surrounding matrix, the radiating crystals will grow at equal rates; the aggregate will be spherical, and the layers of shale will be forced to assume a corresponding position. A rate of supply more rapid along the plane of stratification than in a direction transverse to that plane would give a spheroid with a minimum diameter similarly transverse to the bedding, and a corresponding distortion of the shale mantle. In brief, this hypothesis calls for the production of a compressive force exerted on the surrounding medium by a growing crystal.

Bischof has said that "what we know of causes in the growth of crystals, we have learned in the chemical laboratory. This is our sole guide to a conception of crystallization in the mineral kingdom."[1] It must be confessed that the advocates of the theory of live force exerted by natural crystals have been few, and that almost all derive their whole argument from observations in the geological field, and not from those in the chemical laboratory. Unfortunately, too, many of the examples chosen by them cannot be taken as sure evidence of the exertion of such force by a crystal of a primary mineral, *i. e.*, one that has gathered its molecules, one by one, from a mother liquor, and that by virtue of the attraction of like molecule to like. And this is the case with our calcite molecule. With but few exceptions the argument for live force has been taken from the study

[1] Lehrbuch der chem. phys. Geologie, 2d ed., Band I, p. 140.

of minerals like wavellite, natrolite, and other zeolites, gypsum, serpentine, talc, and other hydrous secondary minerals; possibly pseudomorphs in every case, and if so, of less density, and occupying greater volume than the parent mineral. Such swelling substance can exert active centrifugal force. But we have already noted the fact that this cause of crowding in rock-masses cannot aid us greatly in explaining the Kettle Point concretions.

Basing his statement on such doubtful examples as those just mentioned, Bischof says: "Crystallization is a force which may be compared with that of the expansive force of heat."[1] On the other hand, he quotes Kopp, who opposed Duvernoy in his theory of a mechanical energy of crystallization by showing that a crystal of alum growing in a vessel never does so by accretion on the face upon which the crystal rests at the bottom of the vessel. Kopp thus concluded that the mechanical energy of crystallization must be very slight, if existent at all, in this case, of a crystal of exceptional rapidity of growth that cannot overcome its own trifling weight when immersed in the mother-liquor.[1]

At the same time, certain observers have noted instances where live force seems to have been exerted during growth by crystals or crystalline aggregates, which may not, or, indeed, certainly have not, been pseudomorphous derivatives from preexisting minerals. De La Bèche, speaking of crystalline concretions of selenite and of iron pyrites, stated his belief that, in these cases, chemical affinity was strong enough "to overcome the attraction of cohesion" in the matrix.[2] Dana's example of rifting of quartzite by the growth of a limonitic deposit, and the wedging asunder of parts of a tourmaline crystal by the crystallization of quartz in which the tourmaline lies embedded, are too well known to need more than mention.[3] Similarly, Worthen's disjointed crinoids, the plates of which were gradually separated by the deposition of quartz between them, are cited by Dana as

[1] BISCHOF, Lehrbuch, Band I, p. 134.

[2] Researches in Theoretical Geology, 1834, p. 91.

[3] Manual of Geology, 4th ed., p. 138.

proving displacement by the force of crystallization. More recently, Professor Shaler has appealed to the hypothesis of tensional force to explain the opening of certain vein-fissures, the latter not being explicable by the usually accepted idea of open fissures.[1]

In certain of these cases, it may be agreed that the mechanical force expended seems to have been applied *pari passu* with the process of crystallization; so far as I have been able to find direct statement of the mode of application, each writer signifies his belief that the crystal itself did the work of rifting or of crowding together. We have seen that what little experimentation has already been carried out so far, leaves this interpretation decidedly weakened. The question arises as to whether the energy is set free in the act of crystallization in ways other than in the form of a push exerted by the growing crystal. An answer has suggested itself to me, and I shall briefly outline it, without, I trust, seeming to imply that the idea is anything more than a somewhat highly specialized working hypothesis.

In the Kettle Point shales, saturation of the underground waters by both free and combined carbon dioxide is not hard to imagine. An abundant supply of the gas could be found in the decomposition of the carbonaceous matter in the shales;[2] the monocarbonate of lime is supplied in all necessary quantity from the calcareous bands in the shale and from the underlying Devonian limestones.

Suppose now that a small fragment of carbonate of lime, organic or other, is enclosed in a rock, with a capillary film between mineral and rock. This fragment will act as the immediate stimulus to the decomposition of any sufficiently saturated

[1] Bull. Geol. Soc. Amer., 1899, Vol. X, p. 259.

[2] The analysis of the gas given off from the "east crater" among the Mississippi mud-lumps of 1871 gave the following result: CO_2 9.41 per cent., marsh gas 86.20 per cent., N 4.39 per cent. HILGARD, Amer. Jour. Science, 1871, (1) p. 426. While the percentage of CO_2 is high, we may still regard this analysis as representative of the normal gases given off in the decomposition of vegetable matter buried in mud.

bicarbonated water that may be in contact with it.[1] Monocarbonate is precipitated about the fragment and a double biproduct is formed of water less strongly charged with the bicarbonate than before, and of carbon dioxide, which may be kept in solution in the water. The volume of new monocarbonate, together with that of the biproducts, is greater than that of the original bicarbonate;[2] expansion is necessary. The result would be the development of pressure directed centrifugally with respect to the fragment. This pressure will be the sum of all those minor pressures produced by the single decompositions of bicarbonated water entering by each of a million passages to the point where the solid carbonate is reached. The integrated force may have great efficiency. It would tend to expel the water from the surrounding capillary passages. If the expulsion kept pace with the crystallization, the space between the mineral and the adjacent rock-substance would soon be completely closed and crystallization and growth of the concretion would cease.

But the experiments of Jamin[3] have proved that equilibrium may exist between two unequal pressures affecting the ends of a capillary tube, provided a column of liquid occupying the tube be interrupted by bubbles of air. The presence of the latter excites capillary attraction which is so strong as to take up

[1] It is a familiar fact that crystallization can often be brought about, when not produced by other means, by introducing a crystal of the substance, the crystallizing of which is desired. Further, the mass of substance dissolved in water and coming in contact with a mineral, is very small compared with that of the mineral; if there ensue a chemical reaction, it is the large mass of the mineral that regulates the laws of affinity. Thus, solid carbonate of barium decomposes dissolved bicarbonate of calcium, and solid calcium carbonate decomposes dissolved barium carbonate; à fortiori, solid calcium carbonate will decompose dissolved calcium carbonate, i. e., the bicarbonate. Cf. BISCHOF, Lehrbuch, Band I, p. 114.

[2] That expansion will result has unfortunately not yet been proved by experiment in the case of $CaCO_3$, but it is inferred from the law that expansion of volume follows on the separation of salts from their solutions in those instances where increased pressure aids solubility. Engel has determined that the solubility of carbonate of lime in carbonated water increases very rapidly with an increase of pressure, e. g., doubling with a rise of pressure from one to six atmospheres. Comptes Rendus, Vol. CI, p. 949.

[3] Comptes Rendus, Tome L, 1860, pp. 172 and 311.

several atmospheres of pressure applied at one end of the tube. The force so expended is represented in the compression of the air bubbles and in changing the form of the air menisci; surface tension is thus overcome. The movement of the bubbles progressively decreases in the direction of the greater pressure until one is reached which is not disturbed at all so long as the pressures remain constant. The bubbles act like so many buffers. Any capillary tube filled with water interrupted by any insoluble gas or liquid possessing a lower surface tension than water, will exhibit the same phenomenon. Let us return to our incipient concretion.

Round about the grain of carbonate, there is an infinite network of capillary passages largely occupied by water in the early history of the rock. Along with the water, are gaseous and liquid hydrocarbons that are slowly being evolved by the decomposition of organic matter. The distribution of the hydrocarbons will be such as to bring about capillary attraction, and therewith the possibility of differential pressures within the water-mass, though it be in equilibrium throughout. Thus at the capillary film separating lime fragment and argillaceous wall, we may have great outward pressure unaccompanied by the expulsion of water along the channels leading from the country rock to the fragment. The latter is girt about with a mesh of capillary passages enormously resistant to movement of the contained liquids, and permitting of greater hydrostatic pressure within than without. The form of the mesh itself may change however, without interfering with its function as a buffer. The centrifugal pressure will then be occupied in deforming the rock, and it may conceivably be aided by the expansive energy of the freed CO_2. Fresh supplies of bicarbonated water will slowly diffuse into the capillary space between concretion and rock and further the displacing process. The solid carbonate as it were, keeps pulling a trigger that sets off the reaction of decomposition, which does not occur at a distance from the fragment. The biproduct cannot escape as fast as formed and the country-rock must be crowded away. The deformation is then, analogous

to that produced by the freezing of water in a closed vessel, being caused by a change of volume, and not by the thrust of the crystals as such.

Much of this general scheme can be applied with certainty to the Kettle Point concretions. Bicarbonated water unquestionably was the source of the calcite substance; the decomposition was induced locally at the call of pre-existent carbonate, and the double biproduct described must have resulted. Since the joints in the shale are undoubtedly due to desiccation, it is but fair to suppose that the concretions antedate them. The presence of hydrocarbons during the concretionary growth is likewise reasonable. The resulting surface tension in this deep-lying water would thus bring about capillary action which was especially powerful on account of the extremely small size of the channels through which water could migrate in the shale.

The shape of the growing concretions will depend primarily on the resistances offered to displacement by the shale, and, perhaps, secondarily, to the rate of supply of bicarbonate. From the homogeneous character of the shale, we are led to believe that both of these actions will be nearly equal in all directions throughout the rock, with, however, a slight advantage in power of resistance to be ascribed to the direction at right angles to the plane of stratification. The resulting form of the concretions would, in consequence, be that of a sphere or of a spheroid. The calcite crystals will assume radial positions according to a law of crystal growth that does not concern us here; they will grow outward into the shallow space offered by the outward thrust until the biproduct has slowly diffused through the argillaceous wall.

In conclusion, then, it may be stated that the concretions were formed in place within the shale, that they antedate the period of joint development and final consolidation of the surrounding rock, that the local deformation of the shale accompanied the process of crystallization, and that the energy of the deformation appears to have been derived from the change of volume induced by the breaking up of the bicarbonate into

monocarbonate and fluid biproduct. The introduction of capillarity to explain the existence of differential pressures in the rock-mass cannot be regarded as other than hypothetical. It is hoped that the suggestion may lead to fruitful experimentation; for it is doubtless to the experimental geologist and to the physical chemist that we must finally appeal in determining the source of mechanical energy in deep-seated chemical reactions. The hypothesis should, of course, also be tested by reference to the conditions at other localities where deformation in sedimentary rocks has been produced during the growth of concretions, whether composed of calcite or of other material.

REGINALD A. DALY.

ANTS AS GEOLOGIC AGENTS IN THE TROPICS

A FEW years ago in treating the subject of the decomposition of rocks in Brazil I spoke of ants as geologic agents worthy of consideration[1] My claims for these humble workers were apparently accepted under protest. With this protest I confess I have much sympathy, for if I had not seen with my own eyes so much of these ants and their remarkable deeds I never should have believed half the stories told of them.

Last summer while visiting Brazil again I made a few notes upon the ant-hills in the State of Minas Geraes, and took a photograph showing the kinds of hills so common in certain parts of that state. I went into the interior at one place by the Bahia and Minas railway, which, starting from the coast near Caravellas in the State of Bahia, runs to Theophilo Ottoni (formerly called Philadelphia) in the State of Minas, a distance of 376 kilometers. The first 160 kilometers of the road is over campos of hard baked Cretaceous clays with only patches of forest here and there. Beyond this the rocks are crystalline, mostly gabbros and gneisses, up nearly to the end of the line where the rocks are old metamorphic mica schists, itacolumites, etc., all deeply decomposed. Shortly after leaving the Cretaceous area my attention was attracted by the big ant-hills in the forests. These mounds are from three to fourteen feet high and from ten to thirty feet across at the base. The new ones are steeply conical and the old ones are rounded or flattened down by the weather. In many places these mounds are so close together that their bases touch each other.

An ant-hill at Urucú station, Bahia and Minas railway.

About Urucú station (k. 226) the ant-hills are so thick that the country looks like a field of gigantic potato hills.

[1] Decomposition of rocks in Brazil, by J. C. BRANNER: Bul. Geol. Soc. Amer., 1896, VII, 295-300.

In the vicinity of the city of Theophilo Ottoni there are several old fields apparently abandoned to the ants. The accompanying plate is from a photograph taken on the slope of the hills west of the railway station at this city. The mounds here are all low and rounded as if they were old.

I regret that this picture does not give a better idea of the size and abundance of the ant-hills; unfortunately it was taken when the sun was almost directly overhead, and the view is up the slope and along the side of the hill. Before the photograph was made the man in foreground was sent behind the hill at the foot of which he sits, but though he was over six feet high I could only see the top of his hat. The black lumps shown are hard masses weathered from the large mounds.

Ant-hills in an old field on the Rio Mucury, State of Minas Geraes, Brazil.

In the city of Theophilo Ottoni the streets are cut down in many places through the rock decayed in places. In some of the fresh cuts I observed the holes made by ants penetrating the ground in one place to a depth of ten feet, in another to a depth of thirteen feet, below the surface of the ground; many others were seen at a depth of six, seven and eight feet below the surface.

It goes without saying that the ants do not bore into the hard undecayed rocks, but it seems reasonable to suppose that the opening up of the ground by their long and ramifying underground passages hastens decay, and that the working over of the soil must contribute more or less to the same end.

The impression one gets from the work of the ants along the line of the Bahia and Minas railway — and for that matter in any other part of the tropics — is that they are vastly more important as geologic agents than the earthworms of temperate regions.

Since the publication of my paper upon the decomposition of rocks in Brazil, in which several writers are quoted upon the work

of ants in that country, I have found a few interesting notes upon the subject some of which I quote here.

Speaking of the ants in the River Plate country Sir Woodbine Parish refers to "Corrientes and Paraguay, where whole plains are covered with their dome-like and conical edifices, rising five and six feet in height."[1]

Ant-hills on the hills west of the city of Theophilo Ottoni, State of Minas Geraes, Brazil.

The Robertsons mention ants' nests among the palms near Assuncion, Paraguay, as "thousands of conic masses of earth, to the height of eight and ten feet, and having a base of nearly five in diameter."[2]

Referring to the injury done to crops by the saúba ants the president of the Imperial Instituto Fluminense de Agricultura says: "Among the obstacles with which planters have to contend . . . . there stands perhaps in the front ranks the destructive force represented by the saúba."[3] JOHN C. BRANNER.

[1] Buenos Ayres and the provinces of the Rio de la Plata, by SIR WOODBINE PARISH: 2d ed., p. 252. London, 1852.

[2] Letters on Paraguay, by J. P. and W. P. ROBERTSON, Vol. I, 270–274. London, 1838.

[3] Henrique de Paulo Mascarenhas in the Revista Agricola do Imperial Instituto, December 1883, XVI, 215.

VARIATIONS OF GLACIERS. V.[1]

THE following is a summary of the fourth annual report of the International Committee on Glaciers:[2]

RECORD OF GLACIERS FOR 1898

Swiss Alps.—Of the seventy glaciers which were measured in 1898, twelve are advancing, fifty-five retreating and the others doubtful.[3]

Eastern Alps.—The variations reported last year on the Gliederferner and Vernagtferner are confirmed by further measures. The swelling of these glaciers continues to advance down the valley and to carry with it an increased velocity of motion. When it reaches the end of the glacier there will be an advance of the ice. The majority of the glaciers are retreating, though a few of them are advancing. On the whole the tendency to retreat seems to be increasing.[4]

Italian Alps.—The glaciers of Mount Disgrazia, and those of the south side of the Bernina group are all retreating at the rate of several meters a year.[5]

Scandinavian Alps.—The glaciers of Sweden so far as observed show insignificant changes. They are probably stationary. The velocity of the Stuorajekna near its end was found to be about twice as rapid in summer as the annual average.[6]

Polar Regions.—In 1898, the large glacier between Mt. Hedgehog and South Cape, Spitzbergen, was found to project several kilometers into the sea. This glacier is not shown on former maps, and it is therefore possible that it has recently made a great advance.[7]

[1] The first four articles of this series appeared in this JOURNAL, Vol. III, pp. 278–288; Vol. V, pp. 378–383; Vol. VI, pp. 473–476, and Vol. VII, pp. 217–225.

[2] Archives des Sciences Phys. et Nat., Vol. VIII, pp. 85–115.

[3] Report of Professor Forel.

[4] Report of Professor Finsterwalder.

[5] Report of Professor Marinelli.

[6] Report of Dr. Svenonius.

[7] Report of Dr. Nathorst.

Greenland.— Steenstrup and Drygalski have both concluded from their observations, that the great cold of winter greatly reduces the velocity of motion of the smaller glaciers, but that the large glaciers, nourished by the inland ice, are very little affected by the seasons. Drygalski has found a velocity of twenty meters per day in the great Karajak glacier. The Asakak glacier on the Nugsuak Peninsula has been observed at intervals for fifty years. It retreated nearly a kilometer between 1849 and 1879, and has since then advanced even more. The Sermiarsut glacier no longer reaches tide water as it formerly did, but the other small glaciers of this region show no marked changes. The Blase Dale glaciers on the island of Disco, have continued to retreat since the visit of Professor Chamberlin in 1894.[1]

Canada.— The Upper Bow glacier is slowly advancing, but it has not yet reached the extent indicated by former moraines. Freshfield glacier was advancing in 1897, plowing up the débris in front. Stutfield glacier has been covered with débris by great avalanches, and the melting has thus been retarded. As a result the ice is advancing down the valley and is now in the midst of the forest. It is at least a half mile beyond its former limits. The Illecellewaet glacier has retreated 100 to 150 meters since 1888, and probably 200 meters within the present century.

Himalaya. — The Tarsching glacier apparently retreated between 1850 and 1870, at which latter date it was advancing. It seems to be advancing at present and may block up the valley above it, and cause inundations as it has done before.

Africa. — Dr. Hans Meyer visited the cone of Kibo, the highest point of Kilimanjaro, in 1898 and described the extent of its glaciers. The summit is about 6000 meters high, and the ice streams down on all sides. On the northern and eastern sides the winds are dry, and the glaciers only descend a few hundred meters; whereas on the southern and southwestern sides, the winds are moist and one glacier descends as much as 2000 meters from the summit. There has been a distinct retreat since Dr. Meyer's visit in 1889. Dr. Meyer has also discovered

[1] Report of Dr. Steenstrup.

traces of a glacial period on Kilimanjaro, which confirms similar observations of Gregory further north on Kenia.[1]

Caucasus.—The glaciers in the neighborhood of Mt. Elbruz are retreating at the rate of eight or ten meters a year, with the exception of the Adyl, which has advanced six or seven meters between 1897 and 1898.[2]

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1899[3]

Montana.—Sperry glacier, discovered a few years ago, is retreating—(*L. B. Sperry*).

Mt. Adams, Wash.—This volcanic peak, like the others of this region, has a number of glaciers streaming down its sides. The White Salmon and the Mazama, respectively, on the southwestern and southern slopes of the mountain, are broad and comparatively short masses of ice. Each divides into two tongues. The White Salmon is largely covered with débris, while the surface of the Mazama is clean to its ends, though it has a large lateral moraine. The causes of these differences do not appear.

On the eastern side of the mountain are the Klickitat and Rusk glaciers, both of which lie in deep canyons. They are two or three miles long, the latter being the shorter. The Klickitat is connected with the ice-cap of the mountain through three couloirs, and is also nourished by ice avalanches which fall down the great precipice which characterizes the eastern side of the mountain. The Rusk derives all its material from avalanches. Neither are free of moraines. The other slopes of the mountain are not cut into ravines and the glaciers on the northern side, probably four in number, are not very distinctly separated from each other; they are also thoroughly covered with débris, so that they could not be readily distinguished from a distance.

The Klickitat glacier was retreating in 1890 (*C. E. Rusk*), but no information is available regarding the variations of the others.[4]

[1] Report of Mr. Norman Collie. [2] Report of Mr. Mouchketow.

[3] A synopsis of his report will appear in the Fifth Annual Report of the International Committee. The report on the glaciers of the United States for 1898 was given in this JOURNAL, Vol. VII, pp. 221–225.

[4] The account of these glaciers is taken from descriptions by Professor W. D. Lyman and Mr. C. E. Rusk in the Mazama Magazine, Vol. I, and from a special communication from Mr. Rusk.

Mt. St. Helens.—A glacier on the north side of this mountain was advancing and destroying trees in 1895 (*C. E. Rusk*).

Mount Ranier.—The Nisqually glacier has retreated not less than 100 meters since 1894 (*E. T. Allen*).

Alaska.—Last summer, Mr. E. H. Harrington of New York, invited a number of scientific men to accompany him on a voyage along the Alaskan coast. The full results of the expedition are to be published by the Washington Academy of Sciences.

Twenty-two tide-water glaciers were examined and marks left near many of them by which future changes may be measured.

Photographs and observations made by several members of the expedition show that all the glaciers visited are now retreating except the Crillon glacier on the west side of Mt. Crillon. This glacier does not reach tide-water; it is advancing against the forest and destroying the trees.

Prince William Sound.—Mr. Gannett mapped the glaciers and found that they are all retreating. The Harvard and Yale glaciers have retreated nine miles in a century.[1]

The Columbia glacier is now retreating, but the disturbed ground in front of it shows that it has recently advanced. The young trees growing on this disturbed surface place the date of the advance eight or nine years ago. The Muir glacier made an advance about the same time (*G. K. Gilbert*).

Glacier Bay.—All the glaciers seem to be retreating. In 1879, the three glaciers at the head of the bay were united and three or four miles in advance of their present positions. The Charpentier and Hugh Miller also formed one glacier and extended two or three miles further than they now do. Rendu and Carroll glaciers have suffered decided recessions since 1896 (*John Muir*).

A comparison of photographs taken by Mr. Gilbert in 1899, with others taken by the author in 1892, shows that in that

[1] The Harriman Alaska Expedition, by Henry Gannett, Nat. Geog. Mag., 1899, Vol. X, pp. 507–512; and Bull. Amer. Geograph. Soc., 1899, Vol. XXXI, pp. 345–355.

interval, the Grand Pacific glacier has retreated 500 to 600 yards; and the Hugh Miller 300 to 400 yards; the tide-water end of the Charpentier has receded nearly a mile and the Alpine end is now a mass of disconnected dead ice.

The records of Muir glacier are increasing. We know approximately its extent in 1880 from Professor Muir; and in 1886 from photographs by Professor Wright; and accurately in 1890 and 1892 from surveys by the author; pretty well in 1894 from photographs by La Roche of Seattle, and accurately again in 1899 from surveys by Mr. Gannett. With the exception of a slight advance between 1890 and 1892 the glacier has been pretty steadily receding. At present its extreme point in the middle of the inlet is not much behind its position eight or ten years ago, but the sides have receded fully half a mile. Morse glacier, a tributary on the west, became entirely separated from Muir glacier between 1892 and 1894 and continues to get shorter. Dirt glacier will probably also be an independent glacier before long.

Mr. Otto J. Klotz, of the Canadian Topographical Survey, concludes from a comparison of Vancouver's description of Taylor Bay with its present extent, that the Brady glacier in 1794 was at least five miles shorter than in 1893, when the Canadian survey was made, and that at the earlier date the glacier ended in tide-water. At present its end rests on gravels and does not quite reach the sea. These gravels must then have been laid down in the interval. He also concludes from Vancouver's descriptions and that of Sir George Simpson regarding Stephens' passage in 1841, that all the glaciers south of Fairweather Range have been steadily retreating in the last century. This, however, does not preclude temporary advances of individual glaciers, such as the Pat[illegible], which, according [illegible] *Pacific Coast Pilot* of 1891, was [illegible] and destro[illegible] at that time. The Le Conte g[illegible] about six miles long, and has re[illegible] 1887, when the United States [illegible] was made, and 1893, the ti[illegible]

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Geological Laboratory,
Johns Hopkins University,
March 22, 1900.

[1] Notes on Glaciers of Southeastern ... Klotz: Geog. Jour., 1899, Vol. XIV ...

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STUDIES FOR STUDENTS

THE PROPERTIES OF BUILDING STONES AND METHODS OF DETERMINING THEIR VALUE[1]

I. NECESSARY CONSIDERATIONS IN THE SELECTION OF STONE

QUARRY observations, building inspection, and laboratory examination of building stone are conducted to satisfy the individual and the public that the stone under consideration possesses a color which will remain permanent and inherent qualities which give it a capacity to effectually withstand the atmospheric and other conditions to which it will be subject when in use.

It is my purpose in this number to discuss: (1) Color; (2) the inherent qualities of stone which limit its capacity to withstand atmospheric and other conditions; and (3) the atmospheric and other conditions to which building stone may be subject. In a following number quarry observations, building inspection, and the laboratory examination of building stone will be considered.

[1] This subject has been discussed very freely by geologists, architects, and engineers for twenty or twenty-five years. Many of the ideas expressed in this and the following number are a repetition of the conclusions reached by men who have previously entered this field of discussion. However, it would be a very uncertain task to endeavor to give any one credit for first enunciating the principles herein stated.

The following is a list of the more important American publications which treat, more or less fully, the subject considered in these studies, and to which the reader is referred: The Experimental Tests of Building Stones, by ROBERT G. HATFIELD, Trans. Am. Soc. of Civil Engineers, Vol. XLVIII, pp. 145–151, 1872; Report on the Building Stones of the United States, Appendix of the Annual Report of the Chief of Engineers, U. S. A., 1875; Notes on Building Stones, by HIRAM A. CUTTING, Vermont, 1880; Building Stones of Colorado, by REGIS CHAUVENET, Report of the Colorado School of Mines, pp. 1–16, 1884; The Building Stones of Minnesota, by N. H. WINCHELL, Report of the Geological and Natural History Survey of Minnesota, Vol. I, pp. 142–203, 1884; Special Report on Petroleum, Coke, and Building Stone, The Tenth Census of the United States, 1884; Report on Building Stones, by JAMES HALL, Thirty-ninth Annual Report of the New York State Museum of Natural History,

Color.—The predominant colors of stone are white, gray, brown, red, yellow, buff, blue, black, and green.[1] Ordinarily the color of a rock is not simple but composite, being a resultant of the different colors of the constituent minerals.

The sedimentary rocks on account of the simplicity of their mineral composition approach more nearly to what is known as a simple color than do the igneous. The shades of brown, buff, yellow, red, gray, or blue imparted by a sedimentary rock are mainly attributable to the presence of the oxide, carbonate, or sulphide of iron, bitumen, and carbonaceous matter in the form of graphite. The white and gray colors of marble, limestone, and dolomite may be attributed to the calcite or dolomite of which the rock may be composed.

pp. 186–224, 1886; The Collection of Building and Ornamental Stones in the United States National Museum, by GEORGE P. MERRILL, Smithsonian Report, Part II, pp. 277–520 1886; Igneous Rocks, by J. F. WILLIAMS, Annual Report of the Arkansas Geological Survey, Vol. II, 1890; Building Stone in the State of New York, by JOHN C. SMOCK, Bulletin of the New York Museum of Natural History, Vol. III, No. 10, 1890; Marbles and Other Limestones, by T. C. HOPKINS, Report of the Arkansas Geological Survey, Vol. IV, 1890; Stones for Building and Decoration, by GEORGE P. MERRILL, John Wiley and Sons, 1891 and 1898; The Onyx Marbles, by GEORGE P. MERRILL, Report of the United States National Museum, pp. 539–585, 1893; Marbles of Georgia, by S. W. MCCALLIE, Bulletin No. 1 of the Geological Survey of Georgia, 1894; Notes upon Testing Building Stones, by T. LYNNWOOD GARRISON, Trans. Am. Soc. of Civil Engineers, Vol. XXXII, pp. 87–98, 1894; The Relative Effect of Frost and the Sulphate of Soda Efflorescence Tests on Building Stones, by LEA MCI. LUQUER, Trans. Am. Soc. of Civil Engineers, Vol. XXXIII, pp. 235–256, 1895; Report on Tests of Metals, etc., at Watertown Arsenal; Reports of the United States War Department, pp. 322, 323, 1895; also 1890 and 1894; The Building Materials of Pennsylvania; I, Brownstones, by T. C. HOPKINS, Appendix to the Annual Report of Pennsylvania State College for 1896; The Bedford Oolitic Limestones of Indiana, by T. C. HOPKINS and C. E. SIEBENTHAL, Twenty-first Annual Report of the Department of Geology and Natural Resources of Indiana, pp. 290–427, 1896; Properties and Tests of Building Stones, by H. F. BAIN, Eighth Annual Report of the Iowa Geological Survey, 1898; The Building and Decorative Stones of Maryland, by GEORGE P. MERRILL and EDWARD B. MATHEWS, Report of the Maryland Geological Survey, Vol. II, pp. 47–237, 1898; The Building and Ornamental Stones of Wisconsin, by E. R. BUCKLEY, Wisconsin Geological and Natural History Survey, Bulletin No. IV, 1898. Reference should also be made to the Engineering, Mining, Architectural, Building, Stone, and similar technical journals in which this subject is discussed in current articles.

[1] Speaking from the purely scientific standpoint all of these are not colors, although they are referred to as such in this paper.

When iron occurs in sedimentary rocks, more especially sandstone, it often serves as a cement by which the original particles are bound together. However, it may also occur as an original constituent in the shape of finely disseminated particles. Carbonaceous matter in the form of graphite, or bitumen in the shape of petroleum occurs mainly in limestone and marble, often contributing to these rocks the blue or grayish-blue colors so commonly observed.

Among sedimentary rocks the color varies widely, not only in the same quarry, but often in the same bed. Certain beds in a quarry may have a delightfully cheerful, uniform color, while those immediately above or below may be dull and somber. In many places the coloring matter is distributed through the beds in regular bands, but occasionally it is very curiously disseminated, forming irregular, fantastic figures. White sandstone is often colored with large and small brown spots, while brown sandstone is sometimes similarly variegated with white spots. All stone which is distinctly mottled or irregularly colored is known as "variegated stone."

The color of an igneous rock is usually composite, as a result of the blending of the distinct colors of the mineral particles. The color, however, does not depend entirely upon the colors of the individual minerals, but in part upon the size and distribution of the constituent particles. In some instances the individual grains are sufficiently large to retain their own color, and the stone is spoken of as being mottled.

With respect to color, granites are ordinarily classified as red and gray. Whether a granite belongs to the first or second class will depend mainly upon the red or white color of the feldspar. Many granites contain both red and white feldspar, but as long as the red variety is sufficiently abundant to impart a reddish tone to the rock, it is called red granite. The most brilliant red granites have a preponderance of medium-sized, deep red feldspar individuals. As the feldspar individuals become finer grained and less deeply colored and biotite, amphibole, or pyroxene becomes more abundant, the color is subdued producing dull red effects.

The gray granites are dark or light colored, depending upon the size of the individual grains and the amount and kind of the ferro-magnesian minerals present. The light-colored granites have a preponderance of white feldspar and quartz, with muscovite as the main ferro-magnesian mineral. The dark gray granites contain less feldspar and quartz, and a greater abundance of biotite, hornblende, pyroxene.

Other igneous rocks such as "labradorite granite" with its blue iridescent color, and rhyolite with its almost black color, are commonly met with. The iridescent color of the former is imparted by the abundant porphyritic individuals of labradorite, of which the rock is largely composed. The black color of the latter is due largely to its semi-crystalline groundmass, which often abounds in fine crystals of hornblende. Serpentine is an abundant constituent of some rocks, and as such imparts to them a green color. The dull greenish-gray color so conspicuous among the basic rocks such as gabbro, diorite, and diabase, is imparted mainly by the minerals of the hornblende, pyroxene, amphibole, chlorite, and epidote groups.

The color of a rock when freshly quarried may be almost perfectly white but a few years, or perhaps months, of exposure to the weather may change the color to a buff, or streak it with irregular patches of brown. Such color changes result chiefly from the presence of easily decomposed minerals within the stone itself. The yellow color of many limestones is due to the presence of finely disseminated iron, as the carbonate or sulphide, which has altered to the oxide. If a stone contains either of these the color will change as a natural consequence of exposure to the atmosphere. The oxides of iron are more stable compounds than the sulphide or carbonate, and very seldom cause a change in color.

A change in the color of the stone in a wall may be due to impurities in the mortar, cement, brick, or water used in the construction and not to the presence of easily decomposed minerals in the stone. The committee appointed to investigate the cause of the brown stains on the walls of the State Historical Library

Building at Madison, Wis., reported that the Bedford limestone, out of which the building is constructed, was practically free from ferrous iron, and that the cause of the iron staining was attributable mainly to the cement used in the back wall. This is probably a frequent cause of discoloration, on account of which good stone has been condemned. A common method of preventing the ferrous iron in the brick or mortar of the back wall from coming to the surface, is to use a coat of asphalt between this and the stone facing. A better precaution would be to select lime, cement, and brick from which ferrous lime is known to be absent.

A change of color through the decomposition of iron sulphide and carbonate is manifest mainly among the light colored rocks. The blue or gray limestones and dolomites are often discolored by spots or irregular efflorescent patches of calcium or magnesium sulphate, which appear as a white precipitate on the surface. Their presence at this place is attributed to interstitial water, which comes to the surface bearing soluble salts of magnesium and calcium, mainly the former. Dark colored rocks such as brown sandstone do not discolor, but occasionally they take on a lighter tint after long exposure to the weather. This comes about through the loss of iron oxide which is washed off from the surface by the rains. Decoloration, however, takes place so slowly that it is not an important consideration.

Very often, through long exposure in the quarry a rock, such as the blue limestone of the Trenton formation, is partly or entirely altered in color to a buff. Near the surface, beds may be found that have been completely altered, while deeper in the quarry one passes from those that are partly altered to those that are unchanged. The alteration commences along the joints and gradually passes toward the center of the blocks.

The manner in which a stone is dressed sometimes affects the permanency of its color. A rough dressed stone furnishes a multitude of places in which dust and dirt may lodge, while one which is smooth dressed is free from such places. For this reason there is less danger of the original color being obscured in a smooth

than in a rough dressed stone. On the other hand a smooth dressed stone emphasizes blemishes in color which may be obscured by rough dressing. These color blemishes may be more unsightly than the "tan" of smut and dust, in which case it would be preferable to rough dress the stone.

Fashion, dominated by color, influences the exploitation and the market value of different stones. Until a few years ago brownstone was preferred, both for business blocks and residences, but people became weary of gazing at long rows of somber colored buildings and the fashion changed to light colored stone. At the present time immense quantities of light colored stone are being used, but the fashion will change again in a few years and the pendulum will swing back to brownstone. A judicious use of both would serve to relieve the monotony of long rows of brownstone buildings and of the dazzling glare of white limestone and marble. It is to be hoped that the time will come when the use of neither light nor dark stone will be supreme.

In the large cities, other things being equal, the permanence of color ought to be a factor worthy of consideration in the erection of residences and tenement houses. However, in the construction of business blocks it scarcely warrants serious attention. A white limestone or marble structure erected in the midst of a business portion of a large city soon loses its original color, becoming gray and dingy from the omnipresent smoke and dirt. If the limestone is bituminous and contains a small amount of oil, all the dust and smoke which chances to fall upon it will be retained. The walls of most of the buildings in the business section of our large cities eventually become so begrimed with smoke and dust that it is barely possible to tell whether the stone was originally dark or light colored. One needs to familiarize himself with the characteristic brown and gray shades of stone which have been steeped for years in a smoke and dust laden atmosphere, in order to be able to determine the original colors.

On the whole the dark colored stone shows much less than does the light the effects of smoke and dust. Nevertheless the

only consideration in the selection of stone to be used in the business portion of a large city should be strength and durability.

In the suburban and resident parts of a city and in rural districts, where smoke and dust are trifling matters, the original color will not suffer seriously from external causes alone. In these places beauty is one of the chief ends of architecture, and a judicious scattering of light and dark colored stone buildings adds very materially not only to the appearance of the street as a whole, but also to the beauty of the dwellings individually.

When used for interior decorations, a stone does not suffer materially from atmospheric agencies, and the color will ordinarily remain permanent. The selection of stone for these uses, then, becomes largely a question of taste. A color which harmonizes with the surroundings or matches the other work, is generally considered most appropriate. In the flooring or steps, the capacity which the stone has to withstand abrasion without becoming unduly slippery, and not color, should be the controlling factor.

For monumental purposes the taste of the purchaser is again the main, controlling factor in the color selected. The stones used for monuments are mainly igneous and metamorphic (granite and marble), and as such contain few minerals which will result in discoloration. If pyrite or marcasite are constituents of the stone there will be danger of discoloration. However, the fact that most of the water which falls upon a granite monument is shed by its polished surface, lessens the danger of discoloration, by preventing decomposition.

In the more common uses to which stone is put, such as road making, sidewalks, retaining walls, cribs, breakwaters, bridge abutments, etc., the element of color seldom enters. In the case of retaining walls and sidewalks, which are partially ornamental in nature, color should receive appropriate consideration.

II. INHERENT QUALITIES OF STONE

The capacity which a stone has to withstand the forces tending to destroy it, is known as durability, and depends upon the

mineralogical composition, and the texture or state of aggregation of the mineral constituents. A consideration of the mineralogical composition implies reference to the characteristics of the different kinds of minerals and their relative abundance. By texture is meant the size, shape, manner of contact, and arrangement of the mineral particles. The strength, hardness, elasticity, structures, the effect of alternating heat and cold, and the effect of acids, depend upon both the mineralogical composition and the texture. The specific gravity as ordinarily computed depends upon the mineralogical composition alone; the porosity on the texture; and the weight per cubic foot on the specific gravity, and porosity.[1]

Mineralogical composition.—The most common minerals that enter into the composition of building stones are quartz, feldspar, mica, calcite, dolomite, kaolin, pyroxene, amphibole, and serpentine. These minerals have a respective hardness of 7, 6, 2–3, 3, 3.5–4, 1, 5–6, 5–6, 3–4. With the exception of quartz they all have one or more well-developed cleavages.

Quartz is perhaps the commonest of these minerals. It is the hardest, but probably neither the strongest nor most elastic.[2] Under ordinary conditions of temperature and pressure it is little, if at all, acted upon by the common acids. These conditions, combined with the fact that it possesses no ready cleavage, makes it one of the most durable and stable rock-forming minerals.

Feldspar is also a very common mineral, especially in the igneous rocks. It is softer than quartz, but probably stronger and more elastic. It cleaves readily in two directions. Under ordinary conditions of temperature and pressure it is little acted upon by the common acids. In the quarry, decomposition of

[1] It has been customary to consider the minerals of igneous rocks as primary, and secondary, while the secondary mineral matter in sedimentary rocks is known as cement. In this paper minerals are considered without reference to their origin, and therefore the terms secondary, primary, and cement, have been purposely omitted.

[2] Thus far I have been unable to obtain the crushing strength or coefficient of elasticity of the common minerals. I expect that these constants have been determined although my attempts to obtain them have been unsuccessful.

feldspar takes place very slowly, but owing to the fact that it often occurs in granite and other rock of great age, it is frequently in an advanced stage of alteration. The alteration products of feldspar are objectionable only in so far as they yield more readily to disintegration.

Mica is also a very common mineral, occurring most abundantly in the metamorphic rocks. The ready cleavage by which the mineral splits into thin plates, provides an easy passage for water, by which disintegration proceeds more rapidly than in the associated minerals. Mica is undesirable in proportion to the size of the individuals. If present in small isolated flakes, as it ordinarily occurs in sandstone, it is scarcely less durable than quartz and feldspar, but if the individuals are large or the flakes clustered together, disintegration will proceed more rapidly. Decomposition through chemical agencies goes on very slowly.

Calcite is almost as common as quartz, although far less permanent at the surface of the earth. It possesses three prominent cleavage directions, on account of which it disintegrates quite readily. The hardness, and probably the strength and elasticity, are all less than in quartz. It is quite easily soluble in carbonated waters and is readily acted upon by cold, dilute hydrochloric acid.

Dolomite differs from calcite mainly in its somewhat greater hardness, and the greater difficulty with which it dissolves in cold dilute hydrochloric acid. Its cleavage, hardness, strength, and elasticity are such that it disintegrates almost as readily as calcite, although it is taken into solution somewhat more slowly.

Kaolin is an important constituent of slate, being however, mainly of secondary origin. It is one of the softer minerals, has a perfect cleavage, and readily disintegrates. It is not acted upon chemically except under the most favorable conditions.

Pyroxene is one of the less important building-stone minerals. It cleaves perfectly in two directions, and breaks down slowly through mechanical abrasion. It gradually decomposes in the quarry when in the presence of water.

Amphibole has about the same strength and capacity to withstand abrasion and chemical influences as pyroxene.

Serpentine occurs in certain green colored rocks, such as verde antique, and is usually an alteration product of olivine.

Among the accessory mineral substances in building stones may be mentioned *pyrite*, *marcasite*, *hematite*, *magnetite*, *graphite*, *and bitumen*. Pyrite and marcasite in which the iron occurs partly in the ferrous state decompose quite readily in the presence of moisture, forming ferrous sulphate, which is brought to the surface by capillarity and deposited as iron oxide. Through the decomposition of pyrite, occurring in limestone or dolomite, magnesium and calcium sulphates are formed, which are taken into solution and redeposited at the surface as a white efflorescence.

Hematite and magnetite frequently impart a red, brown, yellow, or black color to the stone, but are not considered harmful.

Carbonaceous matter occurs in the form of graphite, and bituminous matter in the form of petroleum. The gray and black shades of limestone and marble are often due to the abundance of graphite. Petroleum occurs mainly in limestone, and is objectionable on account of the discoloration which is apt to result from the adherence of dust.

The occurrence of gaseous inclusions in the minerals, especially in quartz, is said to be a cause for the shattering of a rock when subjected to high temperatures. To what extent these inclusions influence the results of high temperatures on rock is unknown. The probability is that any temperature which would make these gases active agents of destruction would destroy the rock through unequal expansion of the mineral particles.

The hardness, strength, elasticity, and resistance of the stone to chemical action and alternating temperatures is influenced by the relative abundance of the mineral particles. If the percentage of quartz is large, the hardness is proportionately great—provided the size, shape, arrangement, etc., are constant. The strength and elasticity also increase as the minerals in which these properties are best developed are increased. However, it must be understood that a mineral which is high in the scale

of hardness may have a comparatively low crushing strength and elasticity. Any increase in the percentage of this material will increase the hardness of the rock at the expense of strength and elasticity. Of course, the elasticity, hardness, and strength are not controlled by the one factor of abundance. A rock may consist entirely of the strongest minerals, and yet the size, manner of contact, and arrangement may be such that it will be one of the weakest.

TEXTURE OR STATE OF AGGREGATION

As outlined above the texture of a rock has reference to the size, shape, manner of contact, and arrangement of the mineral particles. The size of the particles affect the weathering of a stone by increasing the differential disintegration. When the mineral particles are large they disintegrate and weather out most easily, often leaving small depressions, on account of which the surface has a pitted appearance. The larger mineral particles have more pronounced cleavage cracks which increase the rate of weathering. Chemical agents have a better chance to operate and the stone is weakened throughout. Rocks which are composed of small mineral particles may have correspondingly small pore spaces, although the size of the pores is largely controlled by the shape and manner of contact of the grains.

The shape and manner of contact of the grains influence the strength and durability of the stone, as much perhaps as any of its other qualities. If the grains are close fitting the adhesion will be increased and the pore space decreased. When the grains are irregular in outline they usually interlock after the manner of dovetail work, which adds to the strength and lessens the pore space.

Upon the arrangement of the grains depends the laminated schistose, or cleavage structure in rocks. If the mica or other minerals are arranged with their longest axes in a common direction and concentrated along certain planes the rock will possess a capacity to part most readily in that direction and along those planes. The perfection of development of the parting capacity will be influenced also by the size of the grains.

The size, shape, manner of contact, and arrangement of the grains control the size of the pores and the percentage of pore space.[1] The porosity of a rock is an important factor, influencing the danger from alternate freezing and thawing of included water.

The pores, or spaces between the grains, which are connected in such a manner as to allow water to flow from one part to another have been divided for convenience into three classes.

The first class consists of small interspaces that exist between the grains of a rock, known as pore spaces; the second class consists of those openings which form along bedding, jointing, and fissile planes, known as sheet openings; the third class are those openings caused by the removal of several or many of the individual grains, commonly known as cavities, caves, or caverns. All of these openings frequently occur in the same rock.

Pores are ordinarily conceived of as being connected so as to form irregular-shaped tubes. Naturally they differ very greatly in size, depending upon the fineness and shape of the original particles composing the rock and the extent to which the interstices have been filled with secondary mineral matter. In the same rock all the pores are never of the same size, although they may have a general correspondence in size. The pores spaces are classified according to size into capillary and subcapillary. . The capillary pores are the larger and the water which they hold is known as the water of saturation. Openings included in this class are over .00002 centimeter in diameter[2] If a rock containing capillary pores is allowed to drain off naturally, a portion of the water will escape, but another portion will

[1] It has been pointed out in another place that pore space in sedimentary rocks depends largely upon the size and shape of the grains and the amount of cement. In general this is true, but the cement itself becomes an individual grain, when once deposited in the interspace of a rock, and the shape and size of the cement grains should be considered. All particles of which a rock is composed should receive consideration as constituent grains of the rock.

[2] Metamorphism of Rocks and Rock Flowage, C. R. VAN HISE, Bulletin of the Geological Society of America, Vol. IX, p. 272.

remain which is known as the water of imbibition. The subcapillary pores are conceived to be of such a size, smaller than .00002 centimeter in diameter, as to contain only the water of imbibition.[1]

As in the case of pores, Professor Van Hise has classified sheet openings which occur along bedding, jointing, or other fissile planes, as capillary and subcapillary, including in the latter all such as are less than .00001 centimeter in thickness.[2]

The third class of openings consisting of cavities, caves, and caverns are a result of the removal of one or more of the grains of which a rock may have been originally composed. They occur most commonly in limestone or dolomite, although present in other less readily soluble rocks.

III. EXTERNAL CAUSES OF DECAY

In the selection of a stone for any purpose a consideration of the climatic conditions under which it is to be placed, is of very great importance. A uniform climate in which the temperature is always above the freezing point is most favorable to long life. A dry climate is conducive to stability, while a moist or humid atmosphere promotes decay. A stone which will withstand the vicissitudes of a moist, temperate climate, where there are long seasons of alternate freezing and thawing, short hot summers, and cold winters, must be of the most enduring kind. The well preserved condition of the monuments of Rome and other cities of the Mediterranean basin, after centuries of exposure, is not due so much to the inherent qualities of the stone, as to the warm, dry atmosphere. The obelisk of Luxor stood for centuries in Egypt without being perceptibly affected by the climate, but after only forty years of exposure in Paris it is now filled with small cracks, and blanched.[3] The same is true of the obelisk in Central Park, New York, from which many pounds of small fragments have fallen.[4]

[1] *Ibid.* [2] *Ibid.*

[3] A. A. JULIEN: Tenth Census, Vol. V, p. 370.

[4] J. C. SMOCK: Bulletin N. Y. Museum, Vol. II, No. 10, p. 385.

The external forces of destruction may be conveniently considered in two classes: (1) those that produce changes through mechanical disintegration and (2) those that produce changes through chemical decomposition. In the case of disintegration the adhesion between the particles or the cohesion of the particles themselves is overcome, and the rock ultimately crumbles into sand or powder. In the case of chemical changes the identity of the mineral particles themselves is destroyed, by the minerals being broken up into other compounds.

The following is a general classification of the agents of mechanical disintegration and chemical decomposition:

I. AGENTS OF MECHANICAL DISINTEGRATION

A. TEMPERATURE CHANGES.
   1. *Unequal expansion and contraction of the rock and its mineral constituents.*
   2. *Expansion occasioned by the alternate freezing and thawing of the interstitial water.*

B. MECHANICAL ABRASION.
   1. *Water.*
   2. *Wind.*
   3. *Feet.*

C. GROWING ORGANISMS.

D. CARELESS METHODS OF WORKING AND HANDLING STONE.

II. AGENTS OF CHEMICAL DECOMPOSITION.

A. WATER-SOLVENT ACTION.

B. CARBON DIOXIDE.

C. SULPHUROUS ACIDS.

D. ORGANIC ACIDS.

Temperature changes.—Injuries to a stone through changes in temperature are occasioned in two ways: (1) By the unequal expansion and contraction of the rock and its mineral constituents, and (2) through expansion due to the alternate freezing and thawing of the interstitial water.

Unequal expansion and contraction of the rock.—The heat conductivity of stone is very low. A stone a few inches in thickness may be heated on one side to a temperature sufficiently high that it will not bear handling, while on the other side the stone may be comparatively cold. The actual expansion of different kinds of stone has been experimentally determined by W. H. Bartlett,[1] in which he obtained the following results:

Granite,	.000004825 inch per foot for each degree F.
Marble,	.000005668 inch per foot for each degree F.
Sandstone,	.000009532 inch per foot for each degree F.

The diurnal changes in temperature in this latitude are often as much as 50° F., while the annual variation in temperature exceeds 150° F. A difference of 150° F. would make a difference of one inch in a sheet of granite 100 feet in diameter.

Each mineral of which a stone is composed has a different rate of expansion. Whenever a stone is heated each particle presses against its neighbors with almost irresistible force. When cooling begins, contraction sets in which initiates stresses pulling the individuals apart. The inequalities in the rate of expansion of the different mineral particles initiate stresses in rocks having a heterogeneous composition, which tend to separate the individual minerals from their neighbors. The result of these alternating temperatures is to weaken the rock and produce small cracks into which water may percolate or roots descend.

Besides the unequal expansion and contraction of the mineral particles, there is an unequal expansion and contraction between the different laminae or hypothetical layers of the rock which are near enough to the surface to be affected by the atmospheric temperatures. The layer at the surface suffers the greatest change in temperature, and is therefore most affected. Each succeding layer is less affected until a point is reached where there is little or no change in the temperature the year around. Owing to the rapid diurnal changes in temperature in some regions forces are constantly at work tending to separate the superficial stratum from those immediately below.

[1] American Journal of Science, Vol. XXII, 1832, p. 136.

The igneous rocks on account of their heterogeneous mineralogical composition, interlocking character of the mineral individuals, and difference in size, are more liable to injury from the diurnal changes of temperature than are the unaltered sedimentaries.

Investigation shows that, in arid regions, very great work is accomplished simply through expansion and contraction due to diurnal temperature changes. Merrill, in his "Rock Weathering," cites an instance in Montana where he found "along the slopes and valley bottoms numerous fresh, concave, and convex chips of andesitic rock, which were so abundant and widespread as to be accounted for only by the diurnal temperature variations. During the day the rocks became so highly heated as to become uncomfortable to the touch, while at night the temperature fell nearly to the freezing point."[1] Livingstone reports the temperature of rock surfaces in Africa to rise as high as 137° F. in the day, and cool off so rapidly by night as to split off rocks weighing as much as 200 pounds. The expansive force of heat is well shown in many of the limestone quarries in Wisconsin, where beds from five to six inches in thickness are for the first time exposed to the heat of a summer's sun. These thin beds become heated throughout their entire thickness and arch up on the floor of the quarry, generally breaking and completely destroying the stone.

Many buildings show the effect of weathering on the side exposed to the direct rays of the sun, while the sheltered side remains uninjured. The only rational explanation for this is found in the diurnal temperature changes. Ordinarily the movements due to temperature changes are necessarily small, but after centuries of time they must invariably result in the weakening and final disintegration of the stone.

Expansion occasioned by the alternate freezing and thawing of the included water.—The effects of diurnal temperature changes as described above, are small when compared with the action of continued freezing and thawing on a rock saturated with water.

[1] GEORGE P. MERRILL: Rocks, Rock Weathering, and Soils, p. 181.

The expansive force of freezing water is graphically described by Geikie "as being equal to the weight of a column of ice a mile high, or little less than 150 tons to the square foot." One centimeter of water at 0° C. occupies 1.0908^{cm} in the form of ice at 0° C. It is this expansion of about one tenth that does the damage when confined water solidifies.

Water finds its way into the rocks through openings or hollow spaces which are everywhere present. Where the pores are large the stone contains water of saturation which is given off with comparative readiness, but the nearer the pores or sheet cavities approach those of subcapillary size, the greater is the tenacity with which the water is retained. One can readily understand how the particles composing a rock may be so closely fitted together, that the pores will be mainly of subcapillary size. Such a rock will contain only the water of imbibition which will be given off very slowly, on account of which the attendant dangers from freezing will be increasingly great. In general it may be said that the danger from freezing will be increasingly great as the pores approach in size those of subcapillary dimensions.

Two rocks, one of which has very minute interstices and the other of which has large pores may have a capacity to absorb equal amounts of water. The former, however, will be in much greater danger from alternate freezing and thawing. Of two equally saturated rocks, one with 10 per cent. and the other with 3 per cent. of pore space, in which the pores are of equal size, the more porous one will be in greater danger of freezing. The percentage of the pore space that is filled with water will also condition the results of freezing. If two thirds of a rock is saturated greater injury will result from its freezing than if only one third were saturated. If none of the pores are more than nine tenths filled with water, the effect of freezing will be nothing, because the increased bulk of the frozen water will no more than fill the spaces between the grains.

The amount of water contained in the pores at a given time depends, of course, upon the amount of water initially absorbed,

the time that has elapsed since absorption, the condition of the atmosphere, the size of the pores, and the position of the stone. It is only in exceptional cases that the stone in the wall of a building is saturated. However, if the pores are of greater than subcapillary size the water of saturation will, as a rule, be quickly removed, except in the lower courses below the water line.

It would, therefore, appear that the most important factor in estimating the danger from freezing and thawing, is the size of the pore spaces, which controls the rate at which the interstitial water is given up. The second factor of importance is the amount of water contained in each of the pores at the time of freezing. The third and last in importance is the total amount of pore space.

T. S. Hunt, in "Chemical and Geological Essays," says: "Other things being equal, it may properly be said that the value of a stone for building purposes is inversely as its porosity or absorbing power." This statement has been quoted by various authorities, one of whom says: "Other things being equal, the more porous the stone the greater the danger from frost." The mistake has often been made of estimating the danger from freezing by the capacity which a stone has to absorb water. Likewise the capacities which two stones have to withstand weathering are constantly being compared from the standpoint of the ratios of absorption. Such estimates and comparisons are very misleading, for one should not only know the capacity which a stone has to absorb water, but he should, above all, know and consider the relative size of the pores.

The injurious effects of the freezing of the "quarry water," as the interstitial water is called by quarrymen, has long since been known to contractors, who generally refuse to accept stone, especially sandstone, which has been exposed to the action of freezing before being seasoned. Where it is possible, quarrymen sometimes flood their quarry during the winter months, in order to protect the stone immediately at the surface.

The openings formed along bedding, jointing and other fissile planes, permit a freer circulation of water than the pores in the

rock. After an abundant fall of rain or when the snow melts in the spring, the cracks, crevices and pores in the rocks cannot carry away the water nearly as rapidly as it collects in these passages at or near the surface. If the temperature at such a time is fluctuating between freezing and thawing, the water will be alternating in a liquid and solid state. As the water congeals again and again the walls are pressed farther and farther apart. The ice acts as a wedge which automatically adjusts itself to the size of the crack, until the opening is sufficiently wide and deep to allow the free passage of the water. Not only are the cracks and crevices very much enlarged and extended through the stresses exerted by the solidification of the water but the stone is in itself materially weakened.

The danger from the freezing of water collected along parting planes must not be confused with the danger attendant upon the freezing of water which fills the pores of the rock. The compact, thoroughly homogenous rocks, without bedding or other parting planes, whether sedimentary or igneous, are in less danger from alternate freezing and thawing than those in which these structures occur.

Alternate freezing and thawing of the included water has been one of the most potent causes for the decay of building stone, more especially that stone which is bedded or otherwise laminated. The most disastrous results occasionally occur from using stone which has not been properly seasoned, and in cases where the stone has been laid on edge instead of on the bed. In the first case the stone is materially weakened throughout by freezing, while in the latter exfoliation or scaling is liable to ensue. The most trying place in a building, in which to place a stone, is at the "water line," where saturation is most common and the greatest alternations of freezing and thawing occur. The conditions are more severe in the case of bridge abutments and retaining walls than elsewhere. In bridge abutments the courses of stone at the level of the water are often badly shelled and broken, while the stone above and below is scarcely injured. It is not uncommon to observe all the courses of a retaining wall

in a dilapidated condition after it has been built a comparatively few years. When the snow melts in the spring the water sinks into the ground and issues through every crack and crevice in the wall. As it collects along these fissile planes it freezes and wedges apart the laminæ of the rocks.

Because the sedimentary rocks more frequently have parting planes than the igneous, they are as a class more apt to suffer from alternate freezing and thawing. On the other hand the sedimentary rocks are sometimes as free from parting planes as the igneous, and are accordingly in as little, or even less, danger from freezing.

The openings known as caves, caverns, and cavities need not occupy our serious attention. Cavities occasionally occur in both sedimentary and igneous rocks used as building stone, but mainly in the former. They do not increase the danger from freezing, owing to the fact that they are seldom filled with water when near the surface. They weaken the rock slightly and often occasion a roughness of the face when they occur at the surface. The cavities are often partly filled with impurities, such as pyrite, which may injure the rock, through the readiness with which they decompose.

From the foregoing we may conclude that an ordinarily well cemented sandstone, which is free from parting planes or stratification, and in which the pores are of greater than subcapillary size, is best suited to withstand alternate freezing and thawing when placed in the wall of a building; assuming that the original strength of the stone is sufficient for the position which it occupies in the wall.

Mechanical abrasion.— One of the most important agents of disintegration in nature is mechanical abrasion, but the rôle which it plays in the destruction of artificial structures is not nearly as important as that of certain other agents.

Mechanical abrasion is accomplished mainly by wind, running water, and shuffling feet working in conjunction with the other agents of disintegration. The beating of the rain against the stone wall may overcome the adhesion between the rock

particles, separate them from one another, and carry them away. These particles may, in turn, as they are carried down the side of the building, wear off other particles, and so on until the bottom is reached. The effects of drifting sand, that are such conspicuous features of the arid regions, are very slight in the temperate zone in which we live. Drifting sand contributes an almost insignificant part to the whole process of disintegration. J. C. Smock, in his report on the building stone of New York, mentions the fact that the ground glass character of many of the window panes in some of the older houses of Nantucket are due to driven sand. The windward sides of many of the monuments in the older eastern cemeteries have lost their polish, while in some cases even the lettering has been destroyed by this same agent. The monuments in the cemeteries of Wisconsin which are located in sandy regions are beginning to show the effects of wind-blown sand. The polish is dulled and the lettering is becoming indistinct.

Besides being subject to the action of wind-blown sand and rain, stone is often used in places where it is abraded by thousands of feet passing over its surface. There is a great difference in the capacity which different stones possess to withstand abrasion. Sidewalks, pavements, and steps may be seen in every city which are more or less worn by constant shuffling of feet over their surfaces.

Growing organisms.— It is a very common occurrence to find lichens and algæ covering the surface of a rock in a quarry. Trees may also be observed sending their roots deep into the crevices and cracks of the rock, and by their growth and expansion huge blocks are often broken from the parent mass. In some of the very soft rocks the writer has observed the finer rootlets ramifying through the body of the rock itself, destroying the adhesion which bound the particles together. Decaying plants are also known to give off organic acids which aid in the decomposition of the rock. Fungi and algæ often attach themselves to the stone, frequently almost entirely covering the exposed surface. The most common form of plant growth

occurring thus is the lichen, which often covers the surface of the rock after the manner of a mat, thereby exerting a protective as well as a destructive influence. The covering which they form serves as a protection against the atmosphere, while the acids incident upon their decay and the mechanical effects of their rootlets penetrating between the grains are a slow cause of disintegration. Algæ are also common, and often occur on the damp parts of a wall, causing discoloration through their own decay and the lodgment of fine dust particles. The effect of allowing creeping vines, such as ivy, to cover the walls of buildings is picturesque, but the practice is certainly injurious to the life of the stone.

Careless methods of working and handling.—The natural forces of destruction have been greatly accelerated, either through the ignorance of quarrymen and their total disregard for proper time and methods of quarrying, or through the carelessness of workmen in cutting, carving, and laying the stone used in building construction. There are probably thousands of buildings, constructed out of stones, the lives of which have been shortened at least one half by improper methods of quarrying and handling.

Quarrymen have been found moving stone with heavy charges of powder, or even dynamite, expecting to obtain dimension stone for building purposes. The heavy charges of powder not only destroy a large amount of stone, but they also shatter the cement and produce incipient joints in the blocks which may accidentally remain in dimensions sufficiently large for building purposes. The destruction of the cement and the production of incipient joints not only weaken the rock, but also facilitate the entrance of water, with the attendant dangers from freezing, with which we are already familiar. This method of quarrying not only materially lessens the value of the salable stone, but hundreds of tons of otherwise marketable stone is absolutely destroyed. The use of heavy hammers and sledges in splitting the stone, by striking continuously along one line, shortens the life of the stone in the same manner as heavy blasting.

Much care should be exercised in quarrying stone in order to prevent these unnecessary injuries. So far as practicable, quarrymen should take advantage of the natural joints. Whenever blasting becomes necessary, the Knox system of small charges, properly distributed, is reported to be the least injurious of any method yet employed. The channeling machine, however, is the best method of reducing the stone to dimensions that can be easily handled. Especially in working sandstone and limestone this machine can be employed to advantage.

The time of cutting and dressing stone may also influence in a small way its life It is generally known that during the process of seasoning the water which comes from within the rock evaporates and deposits mineral matter which forms a crust on the surface of the stone. This crust may be formed entirely by the evaporation of the original interstitial water, or it may be added to by water which has been soaked into the stone at a later period and been subsequently brought to the surface.[1] That water, which has been called the water of imbibition, probably carries a much larger percentage of mineral matter in solution than the water of saturation. The water of imbibition is the last of the quarry water to leave the stone, and therefore the crust is not likely to be well formed until the rock has been thoroughly seasoned. If the stone is to be seasoned before being placed in the wall, it is advantageous to have it first cut, dressed, and carved. Not only is it advantageous to observe this rule from the standpoint of future durability, but also from the fact that the stone often works much more readily when first quarried than it does after it has been seasoned. After a crust has once formed it should not be broken, because the softer rock underneath, when exposed at the surface, will disintegrate much more rapidly. For these reasons most stone should be worked and finished, ready for laying in the wall, before it has been thoroughly seasoned.

[1] The addition through saturation and evaporation after the quarry water has been driven off is probably an almost unappreciable amount, depending upon the amount of mineral matter originally in the water.

The manner of dressing a stone also influences in a small way the length of its life. A stone which has polished surfaces sheds water much more quickly and is disintegrated much more slowly than one with rough surfaces. The stone with rough surfaces has many crannies and crevices, in which the water collects and is finally absorbed. Sandstone which has been hammer-dressed is liable at first to disintegrate faster than that which has been sawed, due to a weakening of the cement by the impact of the hammer. In general, it may be said that polished and sawn surfaces shed water most readily, while those that are rock-faced or hammer-dressed, on account of their rough exterior, absorb a considerably larger percentage of the water which falls on their surfaces.

Before a stone is used in the construction of a building it is safer to have at least the water of saturation driven off. As a rule quarrymen are acquainted with the effects of frost upon stone in which the water of saturation still remains, and observe the necessary precautions. There are quarrymen, however, interested solely in the disposition of their stock, who impose upon the ignorance of the public by selling stone which has not been seasoned. Stone should be seasoned not only to escape the danger from freezing, but also to insure safety in handling and laying.

The exfoliation of sandstone in the large eastern cities has been mainly attributed to the fact that much of the stone has been laid on edge instead of on the bed. Laying stone on edge has been practiced at all times, owing to the greater readiness with which stratified or schistose rocks can be dressed along the bed. The greatest tendency to lay stone on edge is encountered in veneer work, but is occasionally met with in heavy masonry.

If the parting planes, which ordinarily furnish the easiest paths for percolating waters, are normal or inclined to the surface of the earth, they will admit the passage of water much more readily than if they are parallel. Thus if a block of stone is placed on edge in a wall, there will be greater danger from the

freezing of the included water than if it were laid on the bed. In case the stone is laid on edge, the pressure required to split off lamina will ordinarily be much less than if the stone is laid on the bed. In the first case the force occasioned by the freezing of the water which collects between the layers is augmented by the superincumbent pressure of the wall. If the stone is laid on the bed, the water is less apt to penetrate along the parting planes, and even though it should circulate with equal freedom in this position, the superincumbent pressure of the wall would tend to force the expansion in directions parallel to the bedding.

Furthermore, when stone is laid on edge the difference in texture of the various laminae are much more strikingly emphasized than where the stone is laid on the bed. When laid on edge the different blocks, as a whole, will exhibit different rates of wear, instead of the minor inequalities ordinarily shown by the different laminae when the block is laid on the bed.

In important structures one ought to avoid laying any stone on edge which shows stratification or schistosity for the reason that in this position it is inherently weaker and permits a more ready absorption of water, with the attendant dangers from alternate freezing and thawing.

AGENTS OF CHEMICAL DECOMPOSITION

In artificial stone constructions the decomposition of the mineral constituents of a rock proceeds much more slowly than disintegration. The forces which are at work breaking down the chemical compounds have a much greater task to perform than those which have simply to overcome adhesion and cohesion.

Water.—The active agent producing chemical changes in the rock is water. Water generally contains in solution, besides mineral salts, one or more acids, either sulphuric, sulphurous, carbonic, or organic. Thus the water is often a very dilute acid solution. As it percolates through the rocks it dissolves small quantities of mineral matter in one place and deposits it in another. Through these agents the minerals composing the rocks of both the igneous and sedimentary series are decomposed, and transfers of large quantities of mineral substances take place.

In the case of building stone the chemical decomposition of the minerals is so exceedingly slow that it seldom affects the strength or life of the stone after it has been placed in a building. Only in the case of limestone, dolomite, or marble, or where iron sulphide or iron carbonate occur in other rocks, is any material deterioration noticeable.

Sulphurous acids.— In the case of decomposition of iron sulphide, in the presence of moisture, the formation of iron oxide is the most conspicuous, although not the only result. The decomposition of the sulphide produces sulphurous and sulphuric acids which, in the case of dolomite, act upon the magnesium carbonate, producing magnesium sulphate, which is often brought to the surface and deposited as an efflorescence or incrustation.

The sulphurous and sulphuric acid gases are mainly present in the atmosphere of large cities where there is a large consumption of bituminous coal. The action of these acids is largely increased if the atmosphere contains a considerable amount of moisture. In London, where fogs predominate and the consumption of soft coal is very large, there seems to be little question but that the effect of these gases is worthy of careful consideration. But in the United States, with the exception of a few of the larger cities, the influence of these agents is comparatively small and needs but a passing mention.

Carbon dioxide.—Wherever water heavily charged with carbonic acid gas is passed through calciferous rocks, more or less of the calcium carbonate is dissolved, lessening the adhesion between the different particles and weakening the rock. In nature the results of this process are very great, but the carbon dioxide has scarcely any appreciable affect on the durability of stone in the walls of a building.

Organic acids.—The influence of organic acids resulting from decaying organisms on the life and strength of a rock, especially in the walls of buildings, is so slight as to barely warrant mention.

E. R. BUCKLEY.

EDITORIAL

[illegible] Committee on Rock Nomenclature [illegible] International [illegible] Congress, which wa[s] [illegible] concerted action o[f] [illegible] petrographers. [illegible] two reports were received from [illegible] representing different countries. They were from [illegible] France, and will be transmitted to the Congress. [illegible] meeting, the wide divergence of views [illegible] members expressing themselves by letter, and [illegible] independence manifested by all, make it impossi[ble] [illegible] committee as a whole to transmit a report to the con[gress]. Each petrographer is expected to present his views i[n] [illegible] coming meeting in Paris.

[illegible] progress toward harmony o[f] [illegible] classification. There is still a wide [illegible] themselves and the method[s] [illegible] dealing with them. While this is to be regretted, it is not to [illegible] abstract petrological, as well as [illegible] the problem. However [illegible] advancement along more or less con[verging] lines that will eventually unite. In the meantime every petrographer [illegible] himself, as is evident from articles [illegible] this JOURNAL and elsewhere.

Professor [illegible] in his discussion of this subject in this volume of the JOURNAL has laid special emphasis on the value of diagrams in conveying ideas of relative quantities of chemical constituents of rocks, availing himself of Brögger's modification of Michel-Lévy's diagrams. The importance of such devices for expressing relative quantities and for permitting ready comparison of many variable factors in an intricate problem cannot

be overestimated. They not only fix in an easily comprehended form facts already vaguely apprehended, but often suggest relationships not previously suspected. With all machines the product turned out depends on the material operated on. And while the machine itself may be perfect, the product may be open to criticism.

The diagrams in question tend to give more definite impressions of the relative quantities of the chemical elements in rocks than are obtained from the usual statements of analyses. But, if instead of actual rock compositions there is substituted an average of various rocks, it is clear that there is danger of placing too much value on the apparently definite expression conveyed by the composite diagram. Everything depends upon what rocks have been grouped together. Defects in grouping vitiate the diagram. For this reason it is desirable to distinguish between the use of graphical methods of presenting an assemblage of diverse quantities, which is highly commendable, and the practice of averaging diverse quantities, which is open to serious criticism.

J. P. I.

Reviews.

Om klimatets ändringar i geologisk och historisk tid samt deras orsaker. [On Changes of Climate in Geologic and Historic Time and their Causes.] By NILS EKHOLM, *Ymer*, Årg. 1899, H. 4, pp. 353–403. Published by Svenska Sällskapet för anthropologi och geografi, Stockholm.

The first section of the paper discusses, in a general way, the causes of telluric temperature changes. The author states at the outset that the temperature of the earth depends upon the ratio of the amounts of insolation and radiation. He thinks that the solar radiation has very likely not been subject to any considerable changes during the time the earth has been an abode of life. But the transparency of the atmosphere to different kinds of heat rays, and hence also to radiation, has, no doubt, varied greatly and caused the great changes in climate known to geology. Only in the second place would he put the eccentricity of the earth's orbit and the inclination of its axis as a cause of climatic changes. He does not think that the eccentricity of the earth's orbit has caused any climatic variations which have left traces known to geologists. But the variations in the inclination of the earth's axis have caused changes of considerable magnitude in the polar regions, and in the adjacent zone, at least as far down as the latitude of 55° in the northern hemisphere.

The old notion that the internal heat of the earth has appreciably affected climatic conditions in geological time must be set aside. The earth was, no doubt, at one time in the same condition in which we now find the planet Jupiter. There was a dense atmosphere filled with steam. After the temperature of this atmosphere of the cooling globe sank below the boiling point of water its vapor rapidly (in a few hundred years) condensed to a boiling sea. While the convection of this sea was in effective action, the temperature of the sea bottom, the upper crust of the earth, was rapidly lowered, which caused the outer crust to crack open as it contracted relatively more rapidly than the interior. This process went on until the radiation of the crust outward

(which grew less and less) equaled the conduction from below. Then there was a resting time. The cracking ceased. Later the conduction of heat from the interior to the crust was smaller in amount than the radiation from the surface. As a result lateral pressure was developed and caused the rise of the land above the sea here and there in folds.

The paper then proceeds to offer proof that the conduction from the heated interior is vanishingly small at present compared with insolation, hence it can cause no appreciable rise in temperature now.

There follow some paragraphs on geological time and the probable age of life on the earth. The author quotes some computations "made by T. Mellard Reade and communicated by Chamberlin" relative to the age of the sea (JOURNAL OF GEOLOGY, Vol. VIII, p. 572). The computations referred to were made by Chamberlin, though this is not explicitly stated in the paper quoted. The estimates made by Nathorst, Phillips, and Geikie are given. The calculations of Lord Kelvin are also discussed. He is said to have made use of such assumptions that the results attained can hardly be regarded as anything more than a mathematical exercise without bearing on the physical problems involved. It is maintained that there are no physical data disproving the high estimates of geological time favored by geologists and biologists.

The headings of the third part of the paper may be rendered as follows: Insolation nearly constant during geological time; changes in the quantity of carbon dioxide in the atmosphere the principal cause of the great climatic changes; the cause of the change in the quantity of carbon dioxide in the atmosphere. The author refers to Lord Kelvin as having made calculations on radiation from the sun, and having reached the conclusion that the mean temperature of the sun has been constantly rising. The author has carried out further these computations in a paper just submitted to Kongliga Svenska Vetenskaps Akademien, entitled *Ueber den Energie-Vorrath, die Temperatur und Strahlung der Weltkörper*, and finds that the rise in the mean temperature of the earth has been compensated by the diminution in the surface of the sun and also by the decreasing efficiency of the convection currents from the interior to the exterior of the sun. Possibly the radiation was less than it is now at the time when the sun's radius was sixty times its present length.

Then follows an account of the researches of Arrhenius. From these some conclusions are drawn. It is estimated that a diminution

of the carbonic acid in the atmosphere to two thirds of its present amount would probably reduce the temperature of the polar regions by 5° C., and a tripling of the present amount would increase the temperature there by 18° to 20° C., the temperature of the Cretaceous period. A few paragraphs are devoted to discussing the amount of carbon dioxide, the cause of its fluctuations. Using a commercial simile, he remarks that the exchanges between the CO_2 consuming processes and the CO_2 yielding processes are carried on with a very small capital, and hence they are proportionately rapid, and as a result are subject to great and fortuitous changes. New carbonic acid is furnished by volcanic activities (Chamberlin, JOURNAL OF GEOLOGY, Vol. VI, p. 611), and by meteors bringing it into the upper atmosphere. Pursuing his commercial simile he remarks that the reserve fund is in the sea. Chamberlin is again quoted on the effect of lime-secreting organisms in the sea and as to the chemical condition of the carbonic acid in the sea.

Over the first ocean the atmosphere very likely became, as time went on, more and more impregnated with carbon dioxide. This is supposed to have taken place after the conduction of heat from the earth's interior had ceased to have climatological importance. This increase of carbon dioxide is believed to have resulted in the rise of temperature which affected the crust of the earth. The temperature of the early Cambrian age is hypothetically placed at 20° C., with a rise during the period of 10° higher temperature. It is estimated that this rise of temperature would cause folds four kilometers in height, if the expansion were concentrated so as to have caused rising in any single place. In a similar way mountains are held to have been formed in the Carboniferous age. By erosion large amounts of the carbonates were carried to the sea, favoring the life of carbonate-secreting animals. By the increase of land and of temperature the consumption of CO_2 was increased, resulting in the withdrawal of much of it. Thus the cold of the Permian age was brought on.

The progressive cooling of the surface temperature during the Permian age is also discussed. A change from 30° to 10° C. is assumed. This brought about a contraction of the outer shell relative to the inner kernel of the earth. The computed relative shrinking of the outer shell is 12.8 kilometers. This shrinkage brought on extensive cracking and volcanic activity, and thus led to an increased production of carbon dioxide. Thus warm climate again resulted, probably lasting

during the Cretaceous and into the Tertiary period. A subsequent period of folding and withdrawal of carbonic acid resulted in the great ice age. After several less well-known climatic changes — some geologists count as many as six different ice periods — the recent period finally arrived with its temperate climate, in which we still live.

To the fundamental causes here discussed as affecting the climatic changes of long duration, a secondary cause may be added, as pointed out by Chamberlin, namely, the continued erosion and denudation of the continents by precipitation. It is evident that this cause intensifies the climatic conditions between cold and warm periods. In a note (p. 375) the author leaves it to the future to decide whether the interglacial periods are due to changes in the atmosphere, or to changes in the inclination of the earth's axis.

Since the cooling of the polar regions of the earth have, on the whole, always been in advance of the cooling of the tropical and temperate zones, our greatest mountains lie in these latter zones. The polar caps have attained a greater solidity and resistance to pressure, and thus the folding has been mostly transferred to other regions.

The sea has served as a great moderator of the climatic changes of long period. *The cause of the latter must be sought in the alternate contraction and expansion of the earth's crust following changes in the mean temperature of the atmosphere.*

The fourth part of the paper has for its subject *the changes in the inclination of the earth's axis to the ecliptic and its influence on climate.* Here is first given a summary of the evidence of changes in the flora and fauna of northern Sweden, since the ice left the peninsula. Since the time of the "Oak zone," the average temperature has fallen 2° C., judging by the fossil distribution of Hazel. Possibly the winter temperature was but little different from the present. Accepting the archeologist's figures as to the time of the appearance of paleolithic man in Sweden, 7000 to 10,000 years back, the highest temperature of the climate of Sweden seems to have occurred at that time. The author then proceeds to show that the Quaternary changes of climate can be readily and fully accounted for by the "long-periodic" changes in the inclination of the earth's axis. He has tabulated Stockwell's calculations (p. 381). These show the inclination to have been small about 9000 years ago, and that it has been increasing since then. He presents a calculation of the length of the mid-summer day (the sun not setting) for Karesuando, the northernmost meteorological station

in Sweden, at the latest minimum and maximum of inclination, respectively 9100 and 28,300 years ago, thus:

28,300 years ago - -	38 days
9,100 years ago - - -	62 days
At present - - -	54 days

Then follow tables showing calculated temperatures (in terms of excess and deficiency compared with the present) for different latitudes during the months of the year at the last maximum (28,300 years ago) and the last minimum of inclination (9100 years ago) north of 80° N. latitude. There was, 28,300 years ago, a deficiency of 5° C. In Sweden the deficiency was from 3½° to 2° C. These figures are all for the summer months. The author is uncertain as to the winter temperatures. In Sweden these would perhaps depend on the gulf stream, as at the present; 9100 years ago the summer heat was 2° to 1.3° C. higher than now, while the winter temperature is uncertain. A time with hot summers occurred 48,000 years ago. Geologists know of no other period of greater heat than the present, except the one 9000 years ago, *since the end of the last glaciation*. The end of the ice age, hence, cannot have occurred earlier than 50,000 years ago. Possibly it is later, but the greater summer insolation 48,000 years ago may have helped in melting the ice.

The last section of the paper relates to *climatological changes in historic time, especially in northwest Europe*. The author discusses recorded observations on the forming and thawing of ice on various Scandinavian waters, ancient stock-raising in Greenland, grape culture, etc., and concludes that the winters have grown milder and the summers cooler during the last 300 years. Some conclusions are drawn from a study of weather records made by Tycho Brahe. A comparative table of snow precipitation for Brahe's time and the present is given as follows.

PER CENT. OF DAYS WITH SNOW OUT OF TOTAL DAYS OF PRECIPITATION.

Years	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1582–1597 (Time of Brahe) -	3	14	38	45	75	63	21
1881–1898 (Present) - -	2	16	37	48	53	46	19

By comparing this table with current temperature, he finds that it is likely that 300 years ago February was 1.4° C. colder than now, March 1° C. colder, and the other months differed either way by less than .2° C.

Finally the author discusses secular temperature changes as indicated by thermometric measurements made in the last 100 or 150 years, and concludes that at Haparanda, Stockholm, and Lund, in Sweden, the January temperature has risen during this time 1° C., while that of August has become somewhat cooler. At Lund, April, June, September, and October temperatures have remained unchanged.

The paper contains five figures. One of these shows the fossil and present distribution of Hazel in Sweden.

This article is particularly interesting to one who has previously read Chamberlin's papers on the same questions. There are several points of coincidence in the two. One of the authors is a meteorologist, the other a geologist, by profession. On the main cause of long-periodic changes of climate both agree. In accounting for minor details the geologist favors meteorologic causes, while the meteorologist seems inclined to accept, with a modification, a hypothesis which has been quite generally favored among geologists.

J. A. UDDEN.

Sveriges temperaturförhållanden jämförda med det öfriga Europas. [The Temperature Conditions of Sweden compared with those of the rest of Europe.] By NILS EKHOLM, *Ymer*, Årg. 1899, H. 3, pp. 221–242. Published by Svenska Sällskapet för antropologi och geografi, Stockholm.

The only portion of this paper that has obvious geological bearing is the statement that the temperature conditions of Sweden, especially the cold winters which sometimes occur, are to be explained rather by exceptional conditions favorable to radiation than by cold winds coming from Siberia. The author shows, among other things, that the recurrence of cold winters in Sweden exhibits a quite definite periodicity of five and two thirds years, or half the length of the sun-spot period.

J. A. UDDEN.

Physiography of the Chattanooga District in Tennessee, Georgia, and Alabama. By C. WILLARD HAYES. United States Geological Survey. Part VII, Annual Report, 1897–8.

In this report the author has done what Gilbert did in his "Geology of the Henry Mountains," namely, has made a study of a region

where the conditions are more or less simple, with a view of establishing principles which may be used in regions of greater complexity. The region concerned is situated in southeastern Tennessee, northeastern Alabama, and northwestern Georgia. It is bounded by the meridians of 84° 30′ and 86°, and by parallels of 34° and 36°, and comprises nearly 12,000 square miles.

The problems considered are as follows: (1) The forms assumed by maturely adjusted streams in a region where the strata are faulted and folded, and where metamorphism has so affected the rock that the original differences have been diminished, leaving a somewhat homogeneous series; (2) the forms assumed by streams when the strata are practically horizontal, and where the beds vary greatly in hardness; (3) the processes by which consequent drainage in a region of folded strata is transformed into subsequent drainage, with the development of anticlinal valleys and synclinal ridges; (4) the present altitude of former base-levels and the determination of the deformations which the region has suffered in recent geological time. These problems are considered under two main heads, namely, "Geomorphology" and "Geomorphogeny."

The Chattanooga district embraces a part of each of the five natural divisions into which the southern Appalachian province has been divided by Powell.[1] Within this region Hayes finds three types of topography: (1) The Western type, including the Cumberland plateau and the Highland Rim, a part of the interior low lands; (2) the Central type, and (3) the Eastern type.

(1) The first or Western type is separated from the other divisions by the Cumberland escarpment, which forms the eastern boundary of the Cumberland plateau. In the northeastern portion of this district streams have hardly begun to cut in the plateau, while to the south and west only remnants of the plateau remain, each remnant retaining the characteristics of the original highland. The plateau is about 1800 feet above sea level, the Highland Rim about 1000 feet, while the low lands, which stretch northwestward to the Ohio River, have an altitude of but 600 feet. Thus it is seen that the Highland Rim is a terrace between the Cumberland plateau and the lowland. (2) The Central type is that of the Great Valley, in which there are three levels or sets of levels. The valleys of the Tennessee and the Coosa rivers are from 600 to 700 feet above sea level. One series of valley ridges reaches

[1] Physiographic regions of the United States: Nat. Geog. Mag., Monograph No. 3.

altitudes of from 900 to 1100 feet, and another altitudes of from 1500 to 1700 feet. (3) The Eastern type comprises the Unaka Mountains and the western portion of the Piedmont Plain.

The formations of this region are divided into two groups: (1) The unaltered sedimentaries which are of varying degrees of hardness and solubility, and (2) the metamorphic and igneous rocks.

The twenty-three formations of the Paleozoic are divided into five subgroups: (1) The lowest six Cambrian formations consist of conglomerates, quartzite, and siliceous shales, and are nearly insoluble. These form the rocks of the Eastern division. (2) Ten Cambrian and Silurian formations, composed for the most part of limestone and shales, are relatively soluble. These occupy the greater part of the Valley or Central division, while a few beds of sandstone and the Knox dolomite give rise to the valley ridges. (3) The Upper formations of the Silurian and the formations of the Lower Carboniferous are the rocks which form the Highland Rim, and also some of the valley ridges. (4) On account of their solubility, the Lower Carboniferous series gives rise to the characteristic topographic forms in the Western division. (5) The durable Coal Measures conglomerates cap the Cumberland plateau and have occasioned the preservation of large areas of its surface.

The second group of rocks, that is, the igneous-metamorphic group, comprises, (1) the feldspathic (easily eroded) rocks which form the larger part of the Piedmont plateau, and (2) the non-feldspathic (resistant) rocks which have given rise to the irregular topography of the Unakas.

In this region Hayes makes out three peneplains or base levels, namely, the Cumberland base level, the Highland Rim base level, and the Coosa base level.

The altitude of the reconstructed Cumberland base level at its southern edge is about 1200 feet. From this altitude it increases to a height of 2000 feet in the central part, and decreases again to 1600 feet along its southern and eastern edges. This gives a gradient of ten feet per mile from the edges to the center, which is steeper than a base level grade should be, and, besides, no base level tract should have such a shape unless drainage radiated from its center, and this does not seem to have been the case. Hayes explains the present form by the hypothesis that in being elevated to its present position the base leveled region was warped into the form of a low dome. Upon

the peneplain are a few remnants above the general level. The Cumberland base-leveling epoch came to an end with the uprising at the end of the Cretaceous.

The Highland Rim is the peneplain next below the Cumberland. It retains a very uniform height, the difference between the northern and southern edges being but little more than existed during the period in which it was base leveled. Upon this plateau also there are monadnocks which represent areas of more resistant rocks.

The altitude of the lowest and youngest peneplain is 700 feet at the south and 800 feet at the northern edge. Here, as upon the other plateaus, there are considerable variations in altitude in different parts of the peneplain. These should not be taken as indicating distinct base levels, but simply the influence of local conditions.

Hayes considers two hypotheses in explanation of these peneplains, namely, subaërial denudation and marine denudation. He finds support for the former only.

The streams of this region belong to three distinct river systems, the Cumberland, the Tennessee, and the Coosa. They are the main agents which have shaped the present topography. There have been periods of stability and relative inactivity, alternating with great revolutions. It is hard to follow all these changes in detail, for the history of each change is in some measure obscured by that of the next. The first cycle of erosion resulted in the formation of the Cumberland peneplain. This cycle began when the land was raised at the end of the Carboniferous, and ended with the uplift closing the Cretaceous. This long period of erosion was not a single cycle, but was composed of a number of more or less distinct cycles, the evidence of which remains even to this day. Hayes has worked out the general courses of the Paleozoic streams in some detail, but no statement would be intelligible without the maps.

When the Cumberland peneplain was raised and warped, and the second cycle of erosion inaugurated, there were signs of activity all along the line. The sluggish streams began again to cut their beds and to fight for the mastery of favorable positions. The development of new streams at the expense of the old, changes in the direction of drainage, and final, almost perfect, adjustment of the streams in this cycle are carefully worked out by the author. This second cycle, while much shorter than the first, extends over a vast period of time. It ended, as did the Cumberland, by a rise of the land and a slight

warping of the surface. The streams again began to adjust themselves to their new conditions, a work in which they are still engaged.

Hayes has made out the following changes which the streams have gone through in reaching their present courses. First, they moved westward to the interior sea as antecedent streams during the first cycle. Then they were diverted southward to consequent courses, and at last flowed westward as subsequent streams.

The way in which peneplains are correlated forms an interesting section of the paper. The types of stream basins as found in the region are vividly described. The maps, of which there are five, repay careful study.

F. H. H. C.

Geology of Minnesota, Final Report, Vol. IV. By N. H. WINCHELL, U. S. GRANT, WARREN UPHAM, and H. V. WINCHELL. Quarto, pp. i–xx, 1–630, with 31 geological maps, 48 photographic plates, and 114 figures. St. Paul, 1899.

This volume, which completes the areal geology of the state, follows its predecessors in the geographic arrangement of the subject-matter. The area covered embraces the northern third of the state, and includes some thirty counties and districts. The bed rock of the region, with the exception of scattered patches of Cretaceous, is almost universally crystalline in character, and is referred to the Archean and Taconic. The thickness of the drift is very great throughout most of the region considered, several counties in the northwestern part of the state presenting no outcrops whatever of the bed rock.

The crystalline rocks in this largely new field have naturally received much attention, resulting in the accumulation of a considerable mass of new facts relating to the Archean and Taconic, especially the former. The interpretations based upon these facts differ considerably from the commonly accepted views as to the character and divisions of the ancient crystalline rocks, and especially as to the assumed representative of the original crust of the earth.

It is to be regretted that the first presentation of a new classification should be somewhat lacking in clearness, but nowhere in the volume is there a satisfactory statement of the divisions into which the various clastic and igneous rocks of the state have been separated, nor of the equivalents in the ordinary classifications. As nearly as

may be judged from the report, the classification of the pre-Silurian rocks adopted by the survey is as follows:

Cambrian (St. Croix, "Potsdam") (Upper Cambrian)		
Taconic (Lower Cambrian)	Keweenawan	Potsdam (clastic) and Manitou (igneous) . . . . Cabotian (igneous)
	Animikie	
	. . . .	
Archean	Upper Kewatin . . . . . . Lower Kewatin	

I. ARCHEAN

1. *Lower Kewatin.*—The rock of the Lower Kewatin is in general designated by the survey as greenstone, and is composed of two divisions: (1) A lower massive igneous greenstone, assumed to represent the original crust of the earth, and (2) an upper series, partly fragmental and partly chemical, including beds of basic tuff, of agglomerate, and of conglomerate, the jaspilytes and iron ores of the Vermillion range, and vast masses of quartz-porphyry. Both the jaspilytes and the porphyry are tentatively held to be the result of chemical precipitation in the Archean ocean, the apparent dikes of the porphyry in the Upper Kewatin being considered as infolded masses, or as intrusions brought about by plasticity due to the subsequent application of heat and pressure.

2. *Upper Kewatin.*—The Upper Kewatin consists of a basal (Ogishke) conglomerate, overlaid by a series of graywackes, argillytes, and a single jaspilyte. The fragmental members are characterized by the presence in greater or less amounts of greenish material supposed to have been largely derived from the waste of the lower Kewatin, and from the Archean volcanoes. The whole series is involved with the Lower Kewatin in vertical isoclinal folds.

All the members of the Kewatin, both Lower and Upper, have been locally strongly metamorphosed, giving rise to clastic gneisses, schists, etc., where the action was simply one of recrystallization, and

to granites, syenites, diabase, gabbro, etc., where complete hydrothermal fusion took place.

II. TACONIC

This is considered as the time equivalent of the Lower Cambrian, and is separated from the Upper Kewatin by a marked unconformity. It is separated into two divisions, the Animikie and the Keweenawan.

1. *Animikie.*—The Animikie consists of a series of graywackes, slates, and quartzites, and the Mesabi iron ore series. The beds vary in dip from nearly horizontal to 45°. There are no known contemporary lava flows, but the rocks are characterized by the presence of numerous sills and dikes of diabase intruded during the interval separating the Animikie from the overlying clastics (Potsdam).

2. *Keweenawan.*—The clastic part of the Keweenawan is considered as Potsdam and is separated from the Animikie by a distinct unconformity. It begins with a basal conglomerate, usually red in color and of varying coarseness, known as the Puckwunge conglomerate, and is followed by quartzites and sandstones interbedded with lava flows of great volume and extent. The sedimentary beds became progressively thicker as the igneous activities waned, finally terminating in the white and siliceous sandstone of the overlying formation (Upper Cambrian). The dip is even more gentle than in the Animikie.

The eruptives of the Keweenawan are divided into two divisions, the Cabotian and the Manitou.

(*a*) *Cabotian.*—The Cabotian includes the great masses of gabbro, anorthosyte, diabase, etc., which in time of origin immediately antedate the Puckwunge conglomerate. In consequence of the great extrusion of igneous material, designated as the "great gabbro revolution," large areas of the Animikie were covered with heated lavas, resulting in the fusion of considerable portions of the former. Contemporary with this flow there were also important intrusions of gabbro as sills and dikes in the unfused portions of the series.

(*b*) *Manitou.*—The Manitou series is made up of a great number of surface flows, showing amygdaloidal and brecciated partings, and alternating with beds of sandstone in the upper portion. The first of the series appear as contemporaneous beds associated with the basal, or Puckwunge conglomerate, but the greater part of the eruptives are of a distinctly later date.

III. CAMBRIAN

The eruptives of the Manitou series gradually cease and give place to whiter and more siliceous sandstones, which in turn give way without any general break to the magnesian and argillaceous limestones of the Upper Cambrian. These Upper Cambrian rocks are of comparatively slight extent and importance in the area covered by the report.

Igneous rocks.—The igneous rocks, both acid and basic, of the Archean and Taconic are regarded as originating from the hydrothermal fusion of the older rocks, mostly from the clastics. The intermediate stages may often be seen.

The igneous rocks are of three classes — granites, diabases, and quartz-porphyries. The granites are of three relative ages, two being Archean and the third Taconic. They are referred to the fused portions of a still earlier acid clastic. The diabases are also of three relative dates, in this case one being in the Archean and two in the Taconic. They are believed to have been derived from the lowest greenstones, or to occur as apophyses of the gabbro, itself a secondary condition of the greenstone. The quartz-porphyry dikes are again of three periods, one each in the Lower and Upper Kewatin, and one cutting portions of the Taconic. They are supposed to have been derived from the great quartz-porphyry mass of the Lower Kewatin, or from some later clastic.

Glacial Geology.— Besides the mass of observations relating to the crystalline rocks, there are a considerable number relating to the glacial geology of the northern portion of the state, but these observations are not systematically discussed with reference to the great problems of glacial geology.

The thirty or more maps included in the report give, in addition to the geology and ordinary topographic features, approximate contours for every fifty feet, which adds greatly to their usefulness and value. The maps are pleasingly colored and neatly executed. The volume is profusely illustrated by photographic reproductions and line cuts. The former, especially, are numerous, and though not always what might be desired in the point of clearness and appropriateness, add materially to the attractiveness and value of the report.

As one reads the report he cannot but be impressed by the great number of observations made and the mass of facts accumulated, but the disconnected and unsystematic manner of presentation, which necessarily follows from the geographical treatment adhered to

throughout the volume, detracts greatly from the value they would otherwise possess. Too much is left to be inferred, and there is always a strong liability of error in the putting together of scattered observations from various localities which the reader is obliged to do for himself in order to obtain an intelligent understanding of the questions treated.

It is proposed in the next volume of the Final Report (Vol. V), nearly half of which is already in type, to take up the systematic geology of the state, and many of the details, upon which are based the extensive changes of classification and the new conclusions regarding the problems of archean geology, are reserved for publication in this volume. It seems better, therefore, to reserve any extended criticism of the proposed changes until the full facts upon which they are based are published.

M. L. FULLER.

The Ore Deposits of the United States and Canada. By JAMES F. KEMP, New York, 1900, 3d edition, rewritten and enlarged. xxiv + 481 pp. 163 illustrations.

It is with pleasure that geologists will welcome the new edition of Professor Kemp's work on ore deposits. It is to be noticed that the revision has been so complete and the additions so numerous as to bring the matter up to the date of publication and make it one of the most valuable works of its kind in this country.

Professor Kemp has undertaken a difficult task in endeavoring to embody in a single volume a serviceable text-book and a work of reference. That he has succeeded is shown in the first instance by its increased use in the colleges and in the second by a perusal of its pages.

The general plan of the work remains about the same as in the former editions. The matter is divided into two parts, the first o which treats of the general features of ore deposits, the underlying geological principles, the minerals important as ores, the gangue minerals, and their sources, the structural features of veins, the filling of veins, and the classification of ore deposits. This part of the work would have additional value, especially to the prospector and engineer, if it were illustrated a little more fully by diagrams. It is true the number of illustrations has been increased from 94 to 163, but there is

still room for more in the first part even though it should be at the expense of some of the excellent half-tones in the second part.

Part II treats of the ore deposits in detail, taking up the metals one by one, beginning with the more common useful metals, as iron, copper, lead and zinc, followed by the precious metals, silver and gold, and closing with the lesser metals. The most important of these, iron and gold, are treated more fully than the others and it is here we find the greatest changes in the new edition. This portion consists largely of a well arranged and classified review of the best literature on each locality, all the more valuable to the investigator because specific references to the original sources of information are given, thus making it a handbook and manual of reference. Field studies and personal observations in many of the leading mining centers have enabled the author not only to present the most salient features, but to supplement this from his own notes.

The features of the new edition that show the most marked changes are as follows: (1) The Lake Superior iron district is completely revised to accord with the enormous developments which have taken place; (2) the part on limonite ores has been expanded; (3) the Butte district has a new description and maps based on the excellent folio of the United States Geological Survey; (4) the same is true of the Cripple Creek and other districts in Colorado; (5) the part on the gold deposits of the southeastern states has been rewritten and enlarged; (6) a description of the Canadian mining districts, which did not appear in former editions, has been added.

T. C. H.

The Fauna of the Chonopectus Sandstone at Burlington, Iowa. By STUART WELLER. Trans. St. Louis Acad. Science, Vol. X, No. 3, pp. 57–129. Plates I–IX. Feb. 1900.

In his series of Kinderhook faunal studies, of which the present paper is the second,[1] Mr. Weller is doing a much-needed work of revision. The rocks now classed as Kinderhook mark the border line between the Devonian and the Carboniferous over an important portion of the Mississippi valley. They were, by the earlier workers, referred at times to both periods, and there was much dispute as to their proper classification and correlation. Finally Meek and Worthen

[1] For first see Trans. St. Louis Acad. Sci., IX, No. 2., pp. 9–51.

proposed the term Kinderhook to cover the beds, and named the Burlington, Iowa, section for one of the three type sections. The best known collection of fossils from Burlington has been that belonging to the University of Michigan, and known commonly as the "White collection." Descriptions of the fossils in this have been published by C. A. White, C. A. White and R. P. Whitfield, and by A. Winchell, and these descriptions have been the ones principally used heretofore in studying Kinderhook species. The descriptions were, however, in many cases unsatisfactory, and were seriously limited in usefulness by the fact that many of the species were not figured. Under the circumstances it is not surprising that the early doubts as to the age and divisions of the Kinderhook have not been altogether cleared away. Mr. Weller has made careful use of the original White and other collections, and has supplemented his data by notes and specimens taken at Burlington. He has found that the Kinderhook includes seven distinct faunal zones, and in the series of papers now being published he is describing and figuring the fossils from these individual zones. It proves that certain of them have strong Devonian affinities, while others are to be assigned to the Carboniferous. Much of the confusion has come from the failure to distinguish the individual bed from which the species were collected. In the case of the Chonopectus sandstone the brachiopods are, for the most part, strongly Carboniferous in aspect. The pelecypods, gasteropods, and cephalopods, are predominantly Devonian as is the larger number of the total of 81 species recognized. The author regards this, however, as a probable instance of the persistance into Carboniferous time of certain favored Devonian forms. The other view, that these are the earliest and initiatory Carboniferous forms appearing in time properly Devonian, is not, however, as yet, excluded.

As a whole the paper is one of wide interest and value, and will prove very suggestive and useful.

H. F. B.

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APRIL—MAY, 1900

EDWARD ORTON.

EDWARD ORTON, born Deposit, Delaware county, N. Y., March 9, 1829, was descended from old New England stock on both sides of the house. His father, Thomas Orton, a Presbyterian clergyman, whose memory is still cherished in northwestern New York, moved to Ripley, N. Y., on the Lake Erie shore soon after his son's birth. There the son grew up amid an agricultural population, sharing their work and their amusements and gaining an intimate knowledge of their needs which affected his whole course in life. As a lad, he is said to have been somewhat shrinking and sensitive to ridicule; always courteous, always considerate of the feelings of others and sternly conscientious.

His father prepared him for college and, at what appears to us the early age of fifteen, he entered the Sophomore year at Hamilton with the class of 1848. The college course of fifty years ago was narrow, carefully avoiding more than very superficial treatment of the inductive sciences and dwelling chiefly upon classics, elementary mathematics and certain philosophical studies. Edward Orton pursued the course faithfully, though there was little in it attractive to one of his tastes, and at graduation he had a well trained mind with a good stock of such

knowledge as the course afforded. The careful drill in linguistics was that from which he derived most profit, and it was in evidence throughout his writings.

After teaching for one year at Erie, Pa., he entered Lane Theological Seminary at Cincinnati, O., to prepare for the Presbyterian ministry, but, before the year ended, his eyesight failed and he gave up study to become clerk on a coasting vessel sailing to Florida. The autumn of 1851 found him in the Delaware Literary Institute at Franklin, N. Y., where, as instructor in Natural Sciences and German, he was expected to teach any subject offered in the very liberal curriculum. The hours were long and the classes numerous, but his enthusiasm infected the pupils, who accompanied him on long field excursions for study of botany and geology. The next year was spent at Harvard in the study of chemistry and botany, after which another year was spent in successful teaching at Franklin. He then entered Andover Theological Seminary to complete preparation for the ministry. He was licensed in 1855, and soon afterward was ordained to act as pastor of the Presbyterian church at Downsville, Delaware county, N. Y.

He resigned his charge in June 1856, to become professor of Natural Sciences in the New York State Normal School at Albany, N. Y. There he had access to the State Museum and was associated intimately with the strong men on its staff. His life in the Normal School was ideal, and his studies in the State Museum were what he had longed for. Everything appeared to be conspiring to his benefit and to great usefulness in his chosen work.

But, early in his theological studies, doubts had arisen in his mind respecting some tenets of the church and these, it is believed, had something to do with the abrupt termination of his studies at Lane seminary. These doubts were made stronger by the surroundings at Harvard and he undertook the study at Andover with an earnest desire to remove them. It contributed to that result at least so far as to render them subordinate and to permit him to assume the Presbyterian ministry. After he

went to Albany, however, the doubts returned and, increasing in intensity, became convictions so strong that he could not consent to remain in connection with his denomination. To avow his opinions, which, being practically those of the Unitarian church, were very unpopular at that time, would involve not only separation from his church affiliations but also loss of his position in the Normal School; for, though that was a state institution, a public discussion of his views might have alienated an influential portion of the community if he had retained his chair. To many men the temptation would have been serious; no longer in the active ministry, he could have concealed his opinions and could have withdrawn from his denomination without discussion, in this way retaining his position, so important as affording not merely support but also opportunity for thorough study. But his sturdy integrity knew nothing of casuistry; he could not be guilty of even negative hypocrisy. He avowed his opinions, gave up his position, lost his income but gained the abiding respect of his associates, both in church and in school.

The only opening immediately available was the principalship of an academy at Chester, Orange county, N. Y., which he accepted and held for six years, fitting young men for college and lecturing on scientific subjects whenever he had opportunity. His duties left little of spare time, but what he had was utilized in study of such natural phenomena as the region presented, especially those connected with agricultural interests — an admirable preparation for his future work.

Professor Orton's intimate friend at Chester was the Rev. Austin Craig, pastor of an independent church near that place. In 1865, Mr. Craig was chosen acting president of Antioch College in Yellow Springs, O., and Professor Orton was made principal of the preparatory department. Soon afterwards he was appointed to the chair of Natural Sciences. He proved himself so wise, so tactful, that, in 1872, he was called to the presidency of the college. But he was reluctant to assume the responsibility and wrote to Dr. Newberry, with whom he was associated on the State Geological Survey, asking advice. In a

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manly way, without self-depreciation, he gave his reasons for hesitation. Dr. Newberry's emphatic reply was that a man's friends usually understand him better than he does himself. The position was accepted and the event proved that his friends were right. His administration was marked with such vigor, and at the same time with such good judgment in dealing with men both inside and outside of the college that he soon became known throughout the state. When the State Agricultural College was organized in 1873, he was made president, and professor of geology.

The organization of a state college with the agricultural land grant as the endowment was a task whose magnitude might well appal a thoughtful man. Local colleges dreaded a powerful rival; farmers demanded a curriculum suited to their conception of agriculture; lovers of the old methods of education feared too much of application to everyday matters; "practical" men insisted that little attention should be paid to theory, and that "practice" should be supreme; politicians saw in the new institution an opportunity to strengthen themselves by grants of positions; while not a few thought the gift from the national government might prove to be another Pandora's box. But happily, the first board of trustees proved to be men of excellent common sense; they recognized that the work of organization, if it were to be done well, would have to be done by one familiar with educational needs, and that without interference. The work was left to President Orton, whose studies of agricultural conditions, carried on so assiduously for many years, supplemented by his work as teacher, professor, and college president, had rendered him familiar with the complex problems involved. The curriculum was planned, not with a view to bringing the greatest number of students at the earliest moment, but with a view to the advantage of the state and of higher education. The wisdom of this course was soon manifest, for, though the number of students was small during the first year, it increased so rapidly, and the scope of the institution was expanded so greatly that in 1878 the name was changed to the Ohio State

University, the older title being recognized as no longer applicable.

But executive duties were never attractive to him; they interfered with his work as a student. Again and again he asked to be relieved from the presidency, but not until 1881 did the trustees feel that the institution could bear a change. At that time, when the university was established and its policy determined, they yielded to his urgent request. Thenceforward he devoted himself to the chair of geology. With characteristic wisdom he became merely a professor, and apparently forgot that he had been president. One finds no room for surprise at the respect and affection with which his colleagues regarded him.

Professor Orton's love for natural science was distinct early in life, but it always leaned toward application to the benefit of somebody, for, in the proper sense of the term, he was a utilitarian. As soon as he was settled at Yellow Springs he began to study the deposits so well exposed in that neighborhood and quickly gained, as no others had done, a thorough understanding of their relations. His collections of fossils, made wisely and scientifically, proved of great service to paleontologists; he delivered lectures upon scientific subjects, accurate, yet devoid of technical language—lectures of a type little known at that time; he was sought as a speaker among farmers, in village lyceums, and at teachers' institutes. Within two or three years he had become the scientific authority for southwestern Ohio. When the geological survey was organized in 1869 he was appointed one of the two assistants, with the southwestern portion of the state as his district.

At that time there were few geologists. The old surveys had ended in the early forties; a few attempts had been made to organize new surveys, but only that in Illinois had attained real success. Some students had gained experience on the government expeditions in the far West, but of trained geologists there were barely a score. Professor Orton belonged to the generation beginning work immediately after the Civil War, but

he had done much more than most of those within reach, so that his assistance was sought eagerly by Professor Newberry on the Ohio survey. He began the investigation of the Silurians and Devonian, which covered most of his district; but some of the higher deposits were reached and he was compelled, under instructions from the director of the survey, to pass beyond the limits of his district and take up discussion of problems which others thought were peculiarly their own. In all respects he was the strong man of the corps. Painstaking and exact in observation; scrupulous in statement; cautious in speculation, he was called upon many times to render decisions in localities respecting which the reports were in conflict. When Dr. Newberry resigned after the publication of Volume III, Professor Orton was placed in charge. The work was in a peculiar condition. At the beginning of the survey the aids were mostly young men with little field experience, this of necessity, as trained geologists could not be obtained. Some of the work done by those observers was very defective, as the writer, one of the inexperienced aids, can testify; county reports, written independently, were not always accordant; even the general section was unsatisfactory, for identifications had been made with horizons in Pennsylvania beyond an area which had not been studied in detail. Prior to Professor Orton's appointment as director, the work along the state line had been completed for the Pennsylvania survey, and the results did not agree with those presented in the Ohio reports. All this can be said without in any wise reflecting upon those connected with the Ohio survey at the beginning, for every man labored conscientiously to the best of his ability, according to the knowledge then available. Their work, though erroneous in some of the details, resulted in great advantage to the state and in important contributions to geology.

But Professor Orton, in taking up the matter anew, saw that these errors, though apparently of slight economic importance, might lead eventually to serious results, and he set himself to correct them. How difficult the task was few can understand,

but the outcome was that masterly presentation of the whole Carboniferous series of Ohio, in which the relations and variations of every prominent bed as it occurs within the state and in adjacent portions of other states are presented in such fashion as to make the discussion distinctively one of the best yet contributed to Appalachian geology. In this the awkward task of correcting the errors of those who had made the original observations is performed with a delicacy rarely equaled. Good work is noted, but errors are referred to in such a way that to discover whose they are would require more labor than anyone would choose to expend. Indeed, the reader is inclined to believe that every error in observation was due to too earnest desire to do faithful work—which is more than half true.

During Professor Orton's term, the petroleum interests attained great importance; the origin of the oil, the mode of occurrence and the laws regulating the flow were studied with great care. At the same time and with equal care problems relating to natural gas were investigated. Professor Orton was recognized quickly as an authority upon all matters respecting petroleum and natural gas, whether scientific or technical, and he was called upon by the Kentucky, New York, and United States surveys to prepare elaborate reports; so that his writings will be the standard reference for years to come. His studies led him to issue appeals to the people of Ohio urging care in husbanding their resources; but these were not received in the spirit in which they were offered. He had the melancholy satisfaction of seeing his forebodings justified by the event. The distribution of fire and pottery clays, studied in reconnaissance by some aids on the Newberry survey, was taken up systematically and a complete investigation made under his direction by his son, who has succeeded him as director of the survey. Building stone, iron ore, glass sands, and other materials of economic interest, all received careful study. Professor Orton's reports prove the intimate relation between pure science and industrial growth.

Throughout his career, while ever anxious to improve the condition of the community by inducing men to utilize the discoveries of geology, he was ever on the alert to advance the

cause of pure science; for he always maintained that only by its rapid advance can the economic side find advance. The debt of geology to Edward Orton is very great, far greater than we are apt to think, for, in his writings, he effaced himself and often gave credit to others for what was rightfully his own. While he did much for science, he did even more for his state, many of whose industries owe the present success very largely to his efforts—efforts due solely to his anxiety for the public welfare and made without expectation of reward, pecuniary or otherwise.

But Professor Orton was more than teacher and geologist. With burdens of exacting character in the university and in the state geologist's office, he found time and opportunity for services in other directions. The city of Columbus lay near to his heart and he was indefatigable in efforts to advance its interests. He was always ready to aid in any organization looking to the public good; even the state's prisoners were objects of his care for many years. He did not neglect his duties as a citizen, but labored to secure proper candidates for political offices. His time belonged to others; he never felt himself his own.

Professor Orton was always impressed with the exceeding value of time, with the importance of utilizing moments. He was as one intrusted with an estate to be improved to the last degree before the owner's return. Every day's work was done as though that were the only day. Such conscientious devotion gave authority to his statements. Whenever his conclusions proved to be erroneous, the error was regarded as merely additional proof of the limitations of the human mind. With this spirit, whatever he did, whatever he wrote, was brought modestly as a contribution to the growing edifice of knowledge and was offered with such self-forgetfulness that recognition of its merit and of indebtedness to him appeared often to be a matter of surprise rather than of gratification. Honors came to him unexpectedly but they came often.

But while thus sensible of responsibility, Professor Orton never carried a burden. He enjoyed the companionship of his fellows; he had a keen sense of the humorous, but his humor never took the form of sarcasm; no sting was attached to any word

that cropped from his lips or pen. Many times he was compelled to assert himself forcibly, even indignantly, but no bitterness could be discovered in his rebukes. He was the incarnation of integrity; a friend who never wavered.

Little wonder that when he died, the loss to science was less regarded than was the personal loss which was felt by so many in all stations and in all callings; that the man was remembered more than a student. Those of us whose acquaintance with him began thirty years ago became attached to him in such fashion that we rejoiced when good came to him, not asking why it came but gratified that it had come to so true a man. The man has gone and now we think often of the student who deserved to the full, and more, all of the recognition which his work received. We can lay a double tribute upon his grave, one to the man whom we loved and one to the geologist who solved so many perplexing problems.

In the midst of his usefulness, in 1890, Professor Orton was stricken by paralysis which rendered his left side useless. Crippled, with his work incomplete, it seemed as though his life was to pass away in darkness. But his mental powers were unaffected and he recovered strength to such a degree that he continued to work until within a short time previous to his death. In 1899 his health gradually declined. When the American Association for the Advancement of Science met in Columbus last year, he gave an address, so much longer and so much more important than that expected from an incoming president, as to lead some to suppose that he did not expect to live until the meeting of this year. Be that as it may, the address was his last word to his fellow-workers in science. He grew perceptibly weaker after the meeting closed and, on October 16, 1899, he passed away suddenly and without pain.

Professor Orton married, in 1855, Mary M. Jennings, of Franklin, N. Y., who died in 1873. The four children of this union still survive. He married Anna Torrey, of Milbury, Mass., in 1875, who, with their two children, survives him.

JOHN J. STEVENSON.

THE GRANITIC ROCKS OF THE PIKES PEAK QUADRANGLE[1]

GENERAL RELATIONS

FEW natural features in the west are better known by name and form than Pikes Peak, which has served so often as a goal for the pioneer and traveler or as a fitting subject for the photographer and artist. Its prominence arises from its position as the landmark first seen by the traveler moving westward, and from the abruptness with which it rises 8000 feet above the plateau at Colorado Springs.

Moreover, the rapid developments in mining at Cripple Creek and the papers[2] that have recently appeared on the subject have increased the interest in the area and have directed thought to its geology.

In the present paper it is proposed to give a summary of the results obtained from a field and detailed laboratory study of the

[1] Published by permission of the Director of the U. S. Geological Survey.

The field work for the present paper was carried on by the writer while a field assistant in the party of Mr. Whitman Cross who directed the work and suggested the problems to be studied. Many of the specimens were collected by Mr. Cross, and his field notes have been used freely. For the constant willingness to give assistance and the freedom in the use of notes, the writer wishes to express his gratitude to Mr. Cross, who furnished the opportunity to study so extensive an area.

[2] WHITMAN CROSS: Intrusive Sandstone Dikes in Granite, Bull. Geol. Soc. of Am., Vol. V., 1894, pp. 225–230; Geology of the Cripple Creek Gold Mining District; Proc. Colo. Sci. Soc., June 4, 1894.

R. A. F. PENROSE, JR.: The Ore Deposits of Cripple Creek, Colo. *Ibid.*

E. B. MATHEWS: The Granites of the Pikes Peak Area, Bull. Geol. Soc of Am., Vol. VI, 1894, pp. 471–473.

WHITMAN CROSS and R. A. F. PENROSE, JR.: Geology and Mining Industries of the Cripple Creek District, Colo. Part I, General Geology, WHITMAN CROSS; Part II, Mining Geology, R. A. F. PENROSE, JR. Sixteenth Ann. Rept. Dir. U. S. Geol. Surv., II, Washington, 1895, pp. 13–217.

W. O. CROSBY: The Great Fault and accompanying Sandstone Dikes of Ute Pass, Colorado, Science, new series, Vol. V, 1897, pp. 604–607. Archean Cambrian Contact near Manitou, Colorado, Bull. Geol. Soc. of Am., Vol. X, 1899, pp. 141–164.

granular igneous rocks comprising the summit of Pikes Peak, and the area to the west of it, included within the Pikes Peak quadrangle of the Geologic Atlas of the United States. The field observations were made during the seasons of 1893 and 1894, and the laboratory studies during the succeeding winters.

The quadrangle studied contains, approximately, 930 square miles and embraces the greater portion of the southern termina-

FIG. 1.—Pikes Peak seen from the plain.

tion of the Front or Colorado range in its *en eschelon* ending east of the Royal Gorge of the Arkansas. The topographic features of the area are the mountain massif on the east, rising rapidly as shown in Fig. 1, from the level of the plateau to the height of 14,108 feet above the sea. Westward from the summit the slope is much gentler, as shown in Fig. 2, to the somewhat dissected plateau of Cripple Creek and Florissant, drained on the north by the tributaries of the South Platte River and on the south by Oil Creek and its tributaries which drain into the Arkansas River The divide between these two drainages does not include the summit of Pikes Peak but passes somewhat to the north and west of the mountain mass.

The rocks of the region represent massive and schistose granites, metamorphic schists, remnants of formations belonging to the Algonkian, Cambrian, Silurian, Carboniferous, Jura-trias, Cretaceous, and Eocene periods, and numerous igneous rocks including basic breccias, massive andesite, andesite breccias, trachyte, rhyolite, phonolite, and nepheline-syenite.

The granites and gneisses of the Rocky Mountains have generally been regarded as part of the Archean complex, but it has been shown[1] that within the main granitic masses of the Pikes Peak area there are many included fragments of quartzite and of schists that show their derivation from sandstones through induration and metamorphism. These sediments are regarded as of Algonkian age, and the granites cutting these strata are accordingly either Algonkian or early Cambrian. It is deemed most in harmony with the facts in the case to refer the granitic eruptions to the late Algonkian period.

FIG. 2.—Pikes Peak from carriage road (13,000), (showing gentler western slope).

The schistosity in the gneisses was produced prior to the Upper Cambrian and this fact, together with the assumed age of the granitic eruptions renders it probable that the squeezing

[1] Pikes Peak Folio No. 7, Washington, 1895.

of the granites is due to earth movements which preceded the Cambrian.

The following pages treat almost exclusively of the granitic rocks of the area.

ROCK TYPES

The greater portion of the area studied, as shown by the accompanying sketch and the more complete map in the folio of the Geologic Atlas,[1] is occupied by granites, gneisses, and associated schistose rocks which form an undulating platform underlying the later formations. The prevailing composition of this complex is that of a typical granite with the addition of a small amount of fluorine, while the characteristic mineral constituents remain the same over an area of more than a thousand square miles, notwithstanding the fact that the exposures are representative of bodies intruded at different periods, and crystallized under somewhat different conditions. The granites are light colored, usually pinkish, holocrystalline aggregates of feldspar, quartz and biotite with occasional hornblende and fluorite. The individual components vary in their size and relative abundance and in the perfection of their crystal form ; but in almost every instance the feldspar is larger, more abundant and somewhat better formed than either the quartz or biotite. These variations in the manner of aggregation and in the size of the constituent minerals give rise to well-defined types of granite which were distinguished and plotted in the field.

Although some sixteen varieties of granite were distinguished during the mapping, later study has shown that all masses of prominence may be referred to one of four clearly defined types which have been named,[2] the Pikes Peak, the Summit, the Cripple Creek, and the Fine-grained types respectively.

PIKES PEAK TYPE

A large part of the area of the accompanying map is occupied by a single type of granite, called the Pikes Peak type, from its

[1] Geological sheet. Pikes Peak folio, No. 7, Washington, 1895.

[2] Bull. Geol. Soc. Am., VI, 1894, pp. 471–473.

prominence in the constitution of the Pikes Peak massif. This type is characterized by the relatively large size of its feldspar and quartz grains and its tendency to form conspicuous feldspar phenocrysts that often attain a diameter of several inches.

The fresh, unaltered granites of this type are coarse-grained aggregates of quartz, perthitic feldspars, and biotite with occa-

FIG. 3.—Pikes Peak type of the granite.

sional accessory hornblende or fluorite and microscopic apatite, zircon, titanite, magnetite, rutile, hematite, limonite, epidote, and allanite.

The grain varies widely from extremely coarse where the feldspar phenocrysts are six inches long to the more normal granite in which the length of the feldspar grains is little more than a quarter of an inch. The usual diameter for the feldspar is about half an inch, and for the quartz, a quarter of an inch to an eighth of an inch. The biotite areas, although generally smaller than the quartz grains, are sometimes a half inch in width. (Fig. 3.)

The texture of this type presents all grades of transition from that in which the feldspar is only slightly larger than the quartz to one in which the feldspar stands out in large, imperfectly formed porphyritic crystals.[1]

The areal distribution of the rocks showing such increase in the development of the feldspar is not clearly defined, although there is a faint suggestion of a concentric wrapping about the lower slopes of Pikes Peak.

A mechanical separation shows the constituent minerals of the Pikes Peak type to be in the following proportions by weight:

Quartz	33.4
Microcline	53.3
"Biotite"	10.7
Oligoclase	2.6
	100.00

The "biotite" includes all of the minerals with a greater specific gravity than 3.0.

The quartz occurs in large irregular or oval, colorless or smoky grains distinctly outlined against the feldspar and biotite towards which it is usually xenomorphic. In one instance, a basal section of quartz presented three systems of cracks intersecting at 60° representing an imperfect rhombohedral cleavage probably due to mechanical deformation. The extinction ranges from completely simultaneous to mottled or undulatory.

The inclusions observed are arranged according to one of three ways. (1) The small and irregularly shaped inclusions occur either in long thin lines parallel to the rhombohedron, in broader unoriented zones, or irregularly massed in definite parts of the quartz individuals. (2) The small, somewhat rectangular cavities are arranged in indistinct lines parallel to their longer directions but not related to the crystallographic directions of the quartz. (3) The fine, hair-like "needles" have a linear arrangement and seem to occur when the other inclusions are

[1] The coarse-grained granite in which the feldspar phenocrysts are large and generally well formed, is sometimes called the "Raspberry Mountain granite," from its conspicuous development on that mountain.

fewer and more evenly disseminated through the quartz. The mineral nature of the last group could not be determined. The individual inclusions are minute apatites and zircons, hematite plates and magnetite.

Quartz occurs in some of the slides as an inclusion in the feldspars. It is probably secondary in both the microcline and the oligoclase, though in the former it may possibly be original. With the feldspar quartz forms micropegmatitic intergrowths in the more weathered and crushed specimens, but this is lacking in the fresh, unaltered rocks.

The feldspars in the Pikes Peak type vary in size, shape, composition, and age. The color is generally pink or gray, or both where there is a zonal structure. The most important feldspar is microcline perthitically intergrown with albite. This always shows the characteristic "microcline twinning" in all sections inclined to the brachypinacoid. The mesh of the rectangular grating is very small in all those instances which are regarded as original. In the small secondary flakes, however, the mesh is much coarser.

The inclusions within the microcline are albite, quartz, oligoclase, biotite, and the earlier products of crystallization. The most abundant are perthitic pegs of albite, and their disk-like cross-sections. The former lie approximately parallel to a steep positive macrodome in a plane normal to the edge (001) (010). The small round disks may easily be confused with the pellucid quartz from which they can be separated only by the use of converged polarized light.

Oligoclase is only of subordinate importance in the Pikes Peak type where it occurs in small light gray-green anhedral areas with characteristic polysynthetic twinning, lamellae showing on the base an extinction angle of $2°-3°$. The inclusions lie close together near the center of the plagioclase plate and are surrounded by a zone of clear feldspar from which they are more or less sharply defined. The cause of the presence and position of these inclusions is not known. The usual explanation based on the increased basicity and consequent instability of the core

may apply, but the same phenomena may be the result of variations in the conditions during solidification. With the less viscous state of the magma during the early stages of solidification the supply of material is abundant and the growth rapid. The imperfections in crystallization increase with the rate of consolidation, through the inclusion of interpositions and the imperfect filling of space. As the magma on cooling becomes more viscous, thereby decreasing the easy transfer of material and the consequent rate of growth, the molecular arrangement of acquired material on the growing crystal is more perfect in its outer zone. This difference in homogeneity between the core and exterior is sufficient to develop a tendency towards molecular rearrangement in the interior whenever the physical conditions are changed. The sharpness of the limits is determined by the growth lines as in twinning lamellae or zonal structures.

Biotite occurs either as individual flakes or small aggregates presenting the appearance of single flakes to the unaided eye. The mica is strongly pleochroic in brown and yellow, and has an optic angle of 10°. Since the plane of the optic axes was found in several instances to lie perpendicular to the leading ray of the percussion figure, much of the mica is probably anomite.

Hornblende is relatively rare in all the granites of the area. It occurs most often in the Pikes Peak type associated with biotite and titanite. The amount of mica decreases somewhat when hornblende is present, while an increase in the latter is generally accompanied by an increase in the titanite. The hornblende-bearing granites occur in somewhat circumscribed areas below Green Mountain Falls, along the railroad east of Florissant and in the hills east of Lake George.

The accessory minerals enumerated on a preceding page occur in varying amounts. They are usually in small crystals, and belong to the earlier stages of consolidation. Titanite and fluorite are of especial interest, since the former has been found only in this type while the latter is rare, though abundant in the Summit type. Neither presents any mineralogical peculiarities.

Among the alteration minerals resulting from the weathering or metamorphism of this type are epidote and sericite associated with the feldspar; and calcite, chlorite, and muscovite accompanying the biotite.

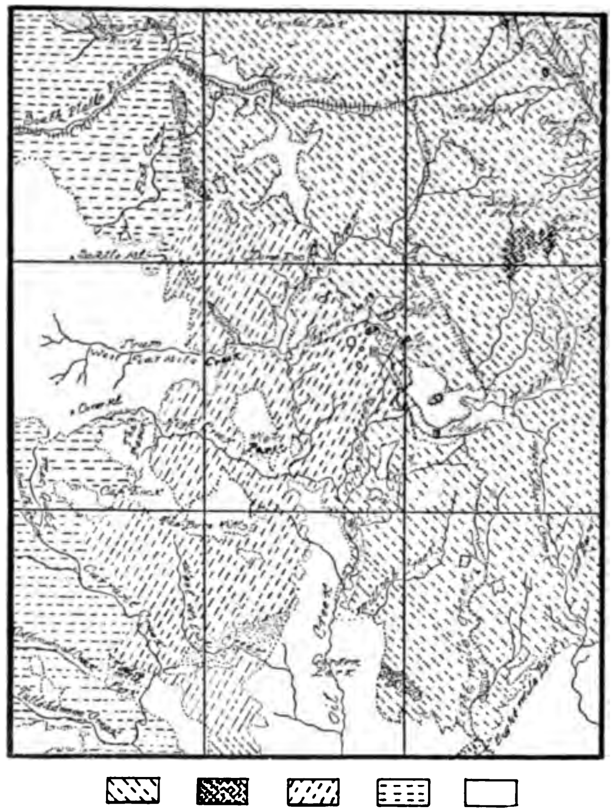

FIG. 4.—Sketch map showing the distribution of the various types of granite occurring in the Pikes Peak quadrangle.

Distribution.—The granites of this type extend northeastward from a sinuous line drawn through the lower slopes of Blue Mountain, Dome Rock, Cripple Creek, and Oil Creek Canyon to the southeastern border of the Pikes Peak Quadrangle. (Fig. 4) The limits beyond the area of the Quadrangle have not been

examined, but are shown in a general way in the maps of the early Hayden survey some miles to the north and east of the Pikes Peak area. Similar rocks have been described from the Platte Canyon in Jefferson county for the Educational Series of the United States Geological Survey.[1]

In its distribution the Pikes Peak type, in the contact with each of the three remaining types distinguished, appears as the older type. It is therefore the oldest granite in the area. The best place for studying the age of this type is in the region about the summit of the massif. Here it is cut by many dikes of the Summit type, which seem to radiate from the central eminence. The actual contact between the two granites is rarely evident in this area, however, as the blocks of the Summit type have formed a slide slope which masks the more easily disintegrating coarse-grained granite. Wherever the contact is observable, as in Wilson Creek southeast of Cripple Creek, the finer rock is seen to cut the coarser. The relations with the Cripple Creek type are poorly defined, as the exposures almost always show small masses of metamorphosed sediments at the immediate contact. The greater age of the Pikes Peak type is shown, however, in several exposures, as, for example, on the north side of Caylor Gulch at an elevation of 8600 feet, where a fine-grained saccharoidal granite of the Cripple Creek type cuts the coarser schistose granite which is correlated with that of the Pikes Peak type.

Weathering.—The processes and results of weathering in the Pikes Peak type are among its most characteristic features. The light pink color becomes darker on exposure and passes into a deep red through a bleaching of the biotite and the subsequent staining of the feldspars and quartz with the liberated iron oxide. The physical changes due to weathering are, however, more manifest. The rock disintegrates before it is decomposed. For this reason the hills are rounded and covered with granite gravel when the disintegrated material remains, and rugged or steep where the débris has been carried away. Fig. 2 gives a view of

[1] Bull. U. S. Geol. Surv., No. 150, Washington, 1898, pp. 172–177.

Pikes Peak from the northwest at an elevation of 13,000 feet, which well illustrates this difference. On the west the mountain slopes with smooth rounded outline into the drainage of Beaver Creek, while on the east the descent is precipitous in ragged cliffs, sometimes resembling huge cyclopean masonry. Counteracting this physical disintegration are chemical changes which

FIG. 5.—Disintegrated bowlder of granite showing surface hardening and disintegration beneath.

protect the rock at first, but ultimately, in conjunction with the physical forces, accelerate the rate of rock-weathering.

The effect of weathering extends for a distance of two or three feet beneath the surface of the exposed rocks. On the exterior there is frequently a dense crust, or glazing, rarely more than half an inch thick, covering a second zone several inches wide, in which the mineral are stained with iron and loosely held together. Beneath this zone the rock is often so incoherent that it seems ready to fall to pieces. The crumbling mass, in turn, passes gradually into the solid rock. Fig. 5 represents a bowlder with the coating on the surface and the disintegrating rock beneath. In this view the upper surface appears

more resistant to the weathering agencies, while the friable rock beneath has fallen away leaving the crust as a projecting edge. Such a crusting over friable material often leads to fantastic shapes, as represented in Fig. 6. The final result of the weathering is the formation of a thick coating of talus and granite gravel, composed of relatively fresh fragments of the rock and its mineral constituents.

FIG. 6.—Fantastic forms due to weathering and surface hardening.

SUMMIT TYPE

The rocks of the Summit type show a very constant texture closely allied to that of granite-porphyry (Fig. 7). They are composed essentially of small gray feldspar phenocrysts embedded in a finely granular aggregate of hypidiomorphic, quartz, smaller feldspars, biotites, and minute grains of fluorite. Microscopic zircon, magnetite, hematite, and micropegmatitic intergrowths of quartz and feldspar are also present.

When fresh the color of the rock is purple, ranging from purple-violet to carmine-purple.[1] As the rock becomes weathered the color becomes less pronounced and fades to light neutral gray and brown.

The minerals composing the Summit type differ very slightly from those described under the preceding type. Quartz is more

[1] Nos. 23*p* and 26*r* of Radde's International Farben scala.

abundant and in smaller areas, and the numerous fine grains in the groundmass are free from much included matter. The larger individuals, however, present the broad zones of inclusions noticed in the preceding type. The porphyritic feldspar is microcline, as in the first type, but here the perthitic intergrowths of albite are much less common. The microcline also

FIG. 7.—Summit type fine grained granite-porphyry.

composes much of the groundmass where it fills the interstices between the grains of quartz. Untwinned clear grains of feldspar, probably orthoclase, are also present in the groundmass in considerable abundance. Oligoclase showing fine twinning lamellae is more poorly developed than in the Pikes Peak type. All of the feldspars are much clouded with alteration products, especially by sericite and some iron compound, either hematite or limonite. The abundant development of micropegmatitic intergrowths of quartz and microcline in this type is noteworthy, as these are practically wanting in the fresh Pikes Peak granite. The

quartz occurs in small oval, or irregular, disks which have the same orientation over considerable areas of the feldspar. Although these disks may lengthen out, they do not have the branching-radial arrangement characteristic of some of the other occurrences.

The biotite occurs in flakes without good crystal outline, and locally shows quite an advanced stage in the alteration towards chlorite and lenses of quartz formed between the foliae. The same slide may show perfectly fresh pieces of biotite associated with that which has become thoroughly chloritized. Unlike the mica of the Pikes Peak granite, the biotite of the Summit type is of the first order with the plane of the optic axes parallel to the principal ray of the percussion figure.

Hornblende, titanite, and magnetite are practically wanting in this type, although a few fresh irregular grains of the latter were noticed in a single slide.

The most characteristic mineral in the Summit type is fluorite. This is present in every section but one made from the Summit granites. It is commonly in small irregular areas and rarely in well-defined crystals. When the crystal contours are evident the little squares suggest either cubes or octahedrons. The mineral is especially characterized by a highly perfect octahedral cleavage which is well developed in the larger areas, but is lacking in the minute crystals. The anhedral areas are clear and either colorless, purple, faintly pink, or green. The pigment is unevenly disseminated through the grains, and seems to be more intense about inclusions than in the clearer parts of the mineral. Between crossed nicols the areas remain perfectly isotropic, and in ordinary light the mineral shows a shagreened surface corresponding to its very low index of refraction. All of the properties enumerated are characteristic of fluorite. The view that this is fluorite is corroborated by the high percentage of fluorine in the bulk analyses and the presence of fluorides in the veins of adjacent areas.[1] Microchemical tests were made, but failed to give conclusive results.

[1] E. g., St. Peter's Dome (Bull. U. S. Geol. Surv., No. 20), and Cripple Creek (Sixteenth Ann. Rept. U. S. Geol. Surv., II, 1895).

Although the gold ores and the fluorite are sometimes intimately associated in the mining area near Cripple Creek, no indications of gold, sulphides, or tellurides were seen in any of the sections of the Summit type.

Distribution.—The rocks of the Summit type are confined to a small area about the Summit and down the western slope of the highest part of Pikes Peak, and the relation between them and the other granites is only seen in a few places. On the main peak there seems to be a system of radiating dikes, but the contacts are not well exposed in place. In Wilson Creek canyon and near the intersection of Spring Creek with the Cripple Creek-Florissant road there are dikes of granites correlated with that of the Summit type which clearly cut the older Pikes Peak granite.

Towards the other granites this type seems to be older, since it is never found in them, while they occur in small masses within its areas.

Weathering.—In the manner of their weathering the rocks of the Summit type show many differences from those of the Pikes Peak type. Instead of disintegrating into massive, rounded bowlders and coarse gravels like the latter, the granite-porphyry breaks up into smaller angular blocks, as illustrated in the familiar views of the Upper Station of the Pikes Peak Railway. These blocks and many of the ledge exposures, moreover, have a glazed crust similar to that observed on bowlders of the Pikes Peak type. What the nature of the process is which produces this surface was not determined in the somewhat hasty survey of the upper portions of the mountain, although the natural surroundings suggest three possible agencies for such polishing, viz., blown sand, ice, and chemical action. The smoothness of the surfaces and the occurrence of polished surfaces in sheltered hollows is against any polishing by sand, while the presence of a crust on somewhat recently formed bowlders and steep slopes, and the absence of glacial striae militate against any explanation based on ice action. The thickness of the shell and the decayed character of the interior, on the other hand, seem to indicate that

this crust is due to chemical action. The great diurnal changes in temperature, the dryness of the air, and the direct action of the sun tend to promote rapid changes in the amount of moisture present, and this in turn would cause alternations of solution and precipitation. Throughout the nights and the winter seasons the rocks receive by capillary action a considerable supply of moisture which during the day and the summer would take some of the material from the interior and carry it to the surface, where there would be rapid evaporation and precipitation. Such action must be slow, as the material carried out is but slightly soluble even under favorable conditions; and yet this very insolubility helps in the final result by rendering at least a portion of the deposited material independent of the rains. The increased amount of silica in the crust seems to corroborate this hypothesis of chemical action.[1] The formation of a crust on the rhomboidal joint blocks, together with the closeness of grain of the rock accounts in great measure for the angularity of the blocks strewn over the summit, and may in part account for the present topographic preëminence of this portion of the massif.

CRIPPLE CREEK TYPE

The granites grouped under this title, compared with those of the preceding types, appear finer than those of the Pikes Peak type and more evenly grained than those of the Summit type. They are finely coherent saccharoidal aggregates of microcline, vitreous quartz, and glistening biotite with occasional microscopic individuals of zircon, hematite, magnetite, and apatite. When phenocrysts are present they are usually microcline, although in an exposure at the Placer Mill northwest of Cripple Creek, broad glistening flakes of biotite are porphyritically developed.

The most prominent constituents are small, rectangular crystals of fresh pink microcline which occasionally reach the length of half an inch (Fig. 8). The twinning network is medium coarse

[1] CROSBY (Merrill, Rock Weathering, p. 255) suggests also the deposition of iron oxide.

and therefore differs from that of the other types. This mesh, however, is not as coarse as that in the smaller, probably secondary, microclines present in the same slides, and in the altered granites more fully described elsewhere. Perthitic intergrowths with albite are not prominent in the majority of the sections, but are very abundant in the slides representing some of the

FIG. 8.—Cripple Creek type of the granite.

granites from the vicinity of Seven Lakes. The microclines of this locality are twinned parallel to the basal pinacoid, according to the Manebach law, and differ only in size and occurrence from the large and beautiful amazonstone and orthoclase so well known from this area. The perthitic lamellae meeting at the composition face (001) form an angle of 147° and in each case lie a few degrees from the vertical axis in obtuse β (parallel to a steep positive orthodome).[1]

[1] In color and texture this rock resembles the well-known granite from Red Beach, Me., described in the Tenth Census, and it is probable that if similar rock can be found where the conditions of quarrying and transportation are favorable it will prove of economic interest.

The irregularly oval grains of quartz composing from one seventh to one quarter of the rock-mass are either clear and vitreous, as in the granites from Seven Lakes, or small and stained with iron, as in the rocks collected in Caylor Gulch. They are somewhat poor in fluid inclusions but show a great number of fine "quartz-needles." The iron-staining occurs as a filling in the cracks, rather than as a minutely disseminated pigment or fine evenly distributed hematite flakes.

Like the granites of the Pikes Peak type, those of the Cripple Creek type do not have very much micropegmatite developed in the fresh specimens, and when it is developed the quartz does not show the arborescent and radiate growths so abundant in the weathered and metamorphosed rocks, but is present in small rounded disks or ovals similar to those described by Romberg.[1]

The plagioclase occurs in small anhedral grains which are older than the quartz and the microcline. They are generally clouded with alteration products which may be either irregularly distributed through the individual; arranged parallel to the twinning lamellae; or concentrated in the center with a surrounding clear zone in similar optical orientation. The twinning lamellae, according to the albite law, are very fine and usually extinguish almost simultaneously parallel to their composition face.

The other constituents, zircon, apatite, and magnetite, show no unusual features and are very sparingly developed.

Distribution.—The granites of the Cripple Creek type are most characteristically developed in the area lying to the west of a line drawn from Lake George to the town of Cripple Creek and thence in a somewhat sinuous line to the waters of Oil Creek. Between this line and the volcanic deposits on the west is a broad stretch of relatively level country considerably dissected on its eastern side by Oil Creek and its tributaries.

The contacts against the Pikes Peak type are generally obscured by the presence of narrow bands of highly metamorphosed schists which were included in the older type and cut by

[1] N. J. B. B-B. VIII, 1892.

the granites of the Cripple Creek type in a manner well shown near the mouth of Arequa Gulch a few miles below the town of Cripple Creek. On the west the contacts with the gneissic granite are generally obscure, though the finer grained may be seen cutting the coarser and more schistose rock in Caylor Gulch at an elevation of 8600 feet.

The manner of weathering and the resulting physiographic forms are intermediate between those of the Pikes Peak and Summit types. The hills are neither so smooth, so bold, nor so massively jointed as those composed of Pikes Peak granite; while the disintegrated fragments are not as compact and angular as those of the Summit type. The mineralogical changes are those common to granitic minerals.

FINE GRAINED TYPE

The rocks included under this head do not occur in well-defined masses extending over large areas but in small dikes distributed throughout the entire area studied. Nor are they so closely allied in their mineralogical and textural features as members of the preceding three groups. Their correlation is based upon their composition and texture, mode of occurrence, age, and present topographic position rather than upon their areal continuity. All of these rocks are fine grained hypidiomorphic granular aggregates of reddish color, composed of quartz, feldspar, and one or both kinds of mica, with small amounts of microscopic fluorite, magnetite, epidote, zircon, and apatite.

The color of these rocks varies from brilliant red to pinkish-white or dull yellow, but is usually bright pink. In the latter case the feldspars are stained by finely disseminated iron oxide. The size of the individual grains is very constant, and rarely exceeds one sixteenth of an inch. Among the individual constituents there are several points of difference from the same minerals in the earlier types. Quartz is more abundant and in grains as large or larger than those of microcline, while incipient granulation shown by a mottled extinction is more frequent.

Among the feldspars, microcline shows a slight increase in the size of its twinning network and the plagioclase a decrease in the size and abundance of its grains. Perthitic intergrowths are practically wanting in these rocks, whether fresh or altered, while micropegmatitic intergrowths are abundant, especially in the slides where the evidences of mechanical deformation are

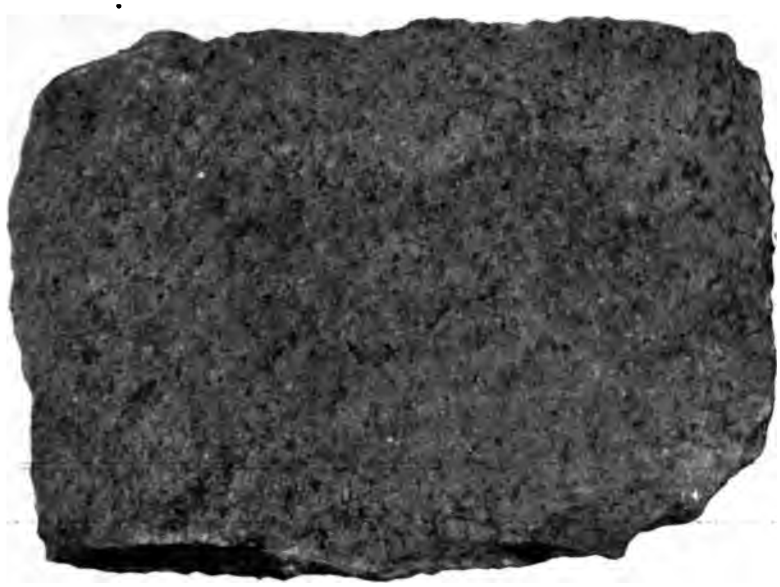

FIG. 9.—Fine grained type of granite.

most numerous. The micas show no unusual features beyond the occasional inclusion of tiny individuals of fluorite showing well-defined crystal outlines in fresh flakes of biotite.

Weathering.—The effect of atmospheric action on the fine-grained granites varies somewhat, but is ordinarily less pronounced than that on the other three types. When the rock disintegrates it usually falls into a mass of angular bowlders of small size, which are quite compact and sometimes covered with a surface glaze. This coating, which is faintly shown in Fig. 9, is much less clearly defined than is that on the Pikes Peak or

Summit types, and it does not appear to be as commonly developed. Ledge exposures of this type are comparatively rare, as the solid rock is usually covered by angular bowlders. The relatively greater resistance to weathering, due probably to the more compact texture of the rock, is clearly brought out in the topographic position of its exposures. When the fine-grained granite occurs in any considerable mass it forms the tops of minor hills and ridges. This is well shown in many places within the area of the map, the best illustration occurring on the subordinate ridges of the slopes of Pikes Peak and in the rugged area between Grouse Hill and Red Mountain, on the sides of the canyon of Cripple Creek.

TABLES SHOWING THE COMPARATIVE ABUNDANCE AND SIZE OF THE CONSTITUENTS OF THE DIFFERENT TYPES

The comparative abundance, size, and development of the various constituents in the four types of granite described in the preceding pages, are summarized in the following tables:

TABLE I. SHOWING RELATIVE ABUNDANCE OF MINERALS

	Pikes Peak	Summit	Cripple Creek	Fine grained
Quartz	abundant	abundant	abundant	predominant
Microcline	predominant	predominant	predominant	predominant
Orthoclase		fairly commonly		
Oligoclase	constant	constant	constant	constant
Perthitic intergrowths	well developed	unusual	not marked	
Micropegmatite	very rare	very abundant	rare	present
Hornblende	present			
Biotite	abundant	abundant	present	present
Muscovite				common
Fluorite	rare	very marked		present
Apatite	constant	rare	rare	present
Zircon	constant	present	constant	constant
Titanite	present			
Epidote	rare			present
Magnetite	present	rare	present	present
Hematite	present		present	present

TABLE II. SHOWING RELATIVE SIZE AND DEVELOPMENT

	Pikes Peak	Summit	Cripple Creek	Fine grained
Quartz				
Size	3–10^{mm} 5^{mm} average	2–4^{mm}	3–5^{mm}	1–3^{mm}
Form	irregular	spheroidal	irregular	irregular
Microline	(Phenocrysts)			
Size	6"×3" to 15×30^{mm}, 20×30^{mm} as	25×15 to 4×7^{mm}	7×5^{mm}	
Form	well developed	well developed	well developed	
Microline	(Groundmass)			
Size	10×15^{mm}	2.×.05^{mm}	1×3^{mm}	1×2^{mm}
Form	irregular	irregular	irregular	irregular
Biotite				
Size	3–4^{mm}	1–2^{mm}	1^{mm}	0.5–1^{mm}
Mode of aggregation	single and aggregate	single and aggregate	single and aggregate	single or aggregate
Texture				
Coarseness ...	coarse	Medium to fine	medium	fine
Arrangement ...	granular to porph. gran.	granitophyric	saccheroidal to orthophyric(?)	granular
Mode of occurrence	large masses	small masses and dikes	large masses	small masses and dikes

The accompanying tables show at a glance the marked similarity in the mineralogical composition, and the equally marked diversity in the textural relations presented by the different types. The diversity in the mineralogical composition of the different types is no more than that due to the presence of occasional orthoclase, hornblende, sphene, muscovite, or epidote in specimens collected over an area of more than nine hundred square miles. These types, it is true, show well developed perthitic intergrowths to be common in the fresh granites of the Pikes Peak type and wanting in the other types; while fluorite and micropegmatite are prominent in the rocks of the Summit type and unusual in the rest of the unaltered granites. The most striking, most constant, and most characteristic differences between the types are, however, in the relative and absolute size

of the constituents, and not in the specific character of the minerals present.

The second table shows a variation in the size of the quartz constituent from grains averaging 5^{mm} in diameter in the Pikes Peak type to those of $\frac{1}{3}^{mm}$ in the fine grained granite. A similar variation is noticeable in the mica, from flakes of $0.5-1^{mm}$ in the fine grained type to those of $3-4^{mm}$ in the Pikes Peak type. The microclines also show a similar change in the same direction, whether they are phenocrysts or not; and in addition the fine-grained granites show no feldspars porphyritically developed. This uniform change in the size of the constituents can only result in the production of a similar variation in the coarseness of grain, as shown in the tables.

Table I, together with the chemical composition of the rocks, brings out the similarity or family likeness existing between the different granites; a likeness that signifies their origin from a common magma relatively rich in silica and fluorine. Table II, with the field relations, substantiates this view and explains the many local differences shown in texture, or mode of aggregation, of the different constituents. The coarse-grained Pikes Peak and Cripple Creek granites formed large masses, while the Summit and fine grained rocks occur in physical conditions sufficiently variable to account for the variations in texture which distinguish the rocks of these types.

CHEMICAL COMPOSITION

The marked uniformity in the mineralogical composition of the various granites from all portions of the area suggests a similar uniformity in the chemical composition. The abundance of quartz and perthitic microcline, with the small amounts of plagioclase, mica, and accessory minerals, indicate a relatively high percentage of silica and the alkalis, with a comparatively small amount of calcium, iron, and magnesium. The presence of fluorite, also, suggests the actually small, but relatively high, percentage of the unusual constituent fluorine. These inferences from the mineralogical composition are fully sustained by the

following complete and careful analyses made by Mr. W. F. Hillebrand of the U. S. Geological Survey.

TABLE OF CHEMICAL ANALYSES

	I (2128)	II (2531)	III (2530)	IV (2369)	V
SiO_2	77.03 1.284	75.17 1.253	73.51 1.225	73.90 1.221	74.90 1.248
TiO_2	.13 .001	.10 .001	.18 .002	.07 .000	.12 .001
Al_2O_3	12.00 .116	12.66 .122	13.28 .129	13.65 .132	12.89 .125
Fe_2O_3	.76 .004	.23 .001	.94 .006	.28 .001	.58 .003
FeO	.86 .012	1.40 .019	.97 .013	.42 .005	.91 .012
MnO	tr.	tr.	tr.	tr.	......
CaO	.80 .014	.83 .014	1.11 .020	.23 .004	.74 .013
SnO	......	tr. ?	......	......	......
BaO	tr.	.03	tr.	tr.	......
MgO	.04 .001	.05 .01	.05 .001	.14 .003	.07 .001
K_2O	4.92 .052	5.75 .061	5.22 .055	7.99 .085	5.92 .063
Na_2O	3.21 .051	2.88 .046	3.79 .061	2.53 .040	3.10 .050
Li_2O	tr.	st. tr.	tr.	tr.	......
H_2O*	.14	.16	.16	.15	.15
H_2O†	.30	.62	.31	.92	.55
P_2O_5	tr.	.03	tr.	.05	.02
Fl.	.36	.31	.55	......	.31
CO_2	......	......	......	......	......
	100.55	100.26	100.38	99.75	......
O less F	.15	.13	.22	.....	......
	100.40	100.13	100.16	99.75	100.26

* Below 110° C. † Above 110° C.

I. (2128.) A coarse grained granite of the Pikes Peak type taken from the western side of the Pikes Peak massif at a place

called Sentinel Point (12,300 feet). Feldspar is the most important constituent, with quartz very abundant in somewhat smaller grains. The mica occurs in both single individuals and in aggregates of minute flakes. A thin section of this rock is composed, almost entirely, of quartz and microcline, the latter showing a few lamellae of perthitic plagioclase.

II. (2531.) A porphyritic granite of the Summit type collected from the divide tunnelled by the Colorado Springs Water-works (elevation about 12,000 feet). This is composed of feldspars and large grains of quartz in a fine grained, reddish to purplish groundmass.

III. (2430.) A fine grained variant of the Summit type collected on the head waters of the Middle Beaver, nearly opposite the Bear Creek road to the Colorado Springs Water-works. The prominence of the biotite against a fine grained groundmass of feldspar, and the peculiar purplish hue due to the disseminated fluorite, are the chief characteristics.

IV. (2369.) A fine grained granite of the fourth type taken from Smith's Gulch not far from Current Creek P. O. This is composed of quartz and microcline with small amounts of mica.

V. An average of the preceding.

The following conclusions based on a comparative study of the analyses seem to be warranted by the figures. When the individual analyses and their average are reduced to molecular proportions and compared with an average of twelve type analyses given by Zirkel[1] and several analyses given by Rosenbuch[2] similarly reckoned, it is seen that they all are richer in silica than the averages given in the text-books, though not richer than individual specimens from many areas. The sum of the alkalis seems to conform to that of the averages but the granites of the Pikes Peak area are relatively richer in potassium. This relation between the alkalis becomes of additional interest when the occurrence of nepheline-bearing rocks near Cripple Creek is considered.

[1] Lehrbuch der Petrographie, 2te. Aufl. II, p. 29.

[2] Elemente der Gesteinslehre, p. 186.

Among the elements represented, fluorine is of the most interest. Although small in amount the still smaller quantities of lime and phosphorus show that there is enough present to satisfy all of the latter even in the form of pure fluor-apatite, and much of the former in the form of fluorite. The possible excess of calcium is so small that the plagioclase plates must be sodium rich oligoclase and the perthitic pegs albite.

The low percentage of iron and magnesium together with the strong pleochroism of the mica explains the relative scarcity of this mineral.

The chemical analyses confirm the microscopic determinations and show that the general magma was of such a composition as might produce a rock composed essentially of a potassium feldspar, perhaps intergrown with albite, and considerable quartz, with small amounts of fluorite and iron rich mica.

RÉSUMÉ

The area included within the Pikes Peak quadrangle is a complex of granites, gneisses and schists overlain by numerous sedimentary and volcanic rocks of later age. The unaltered granites show, over an area of more than a thousand square miles, a notable uniformity in their mineralogical and chemical composition which is marked by the persistent presence of holocrystalline quartz-microcline aggregates bearing small amounts of equally constant biotite. On the other hand, these same rocks show a distinct diversity in the abundance, size, and form of their constituent minerals and the consequent differences in texture.

The variations in texture and composition are as follows:

Pikes Peak type.—Coarse granular to coarse porphyritic: rich in perthitic feldspar, poor in micropegmatitic intergrowths, and fluorite with occasional hornblende and titantite.

Summit type.—Granitophyric; poor in perthitic feldspars but rich in micropegmatite and fluorite.

Cripple Creek type.—Saccharoidal with rectangular feldspars; poor in perthitic feldspars, micropegmatite, and fluorite.

Fine grained type.— Fine granular; poor in perthitic feldspar, micropegmatite, and fluorite but bearing some muscovite.

Emphasis has often been laid on the variations in the chemical or mineralogical composition of masses showing uniformity in their texture. The present instance represents on a large scale the opposite changes. Here there are well-defined differences in texture in a mass of uniform chemical composition. The changes in mineralogical composition are slight, and represent little or no difference in the chemical proportions of the mass except in the case of the fluorite. The other changes are local and partake of the nature of "dark patches."

Besides these original differences in the textures there are others of secondary origin where the feldspar phenocrysts have become lenticular "eyes" and the massive granites have been changed to granite-gneisses.

EDWARD B. MATHEWS.

A NORTH AMERICAN EPICONTINENTAL SEA OF JURASSIC AGE

INTRODUCTION

The following line of investigation is the out-growth of the study of the faunal and stratigraphical conditions as they are expressed in the Jurassic formation of the Freeze-Out Hills in southern Wyoming.[1] In making these investigations the writer has been led to test, in the light of new doctrines[2] and more recent observations, certain prevalent opinions bearing on Jurassic faunal geography. In connection with these investigations there arose also questions concerning which no definite statement

[1] LOGAN: Kansas Uni. Quart., April 1900.

[2] See papers by DR. T. C. CHAMBERLIN on: "A Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. VI, p. 598; "The Ulterior Basis of Time Divisions," *ibid.*, p. 449.

of opinion has as yet appeared in our geological literature. Among the lines of investigation which suggested themselves were the following: (1) The nature and extent of the interior Jurassic sea; (2) the relation of the interior fauna to other faunas; (3) the connection or connections of the sea with the ocean; and (4) the causes for the lack of communication between the Interior province and the Californian faunal province.

Some of these questions, notably the second and fourth, have already received a somewhat exhaustive discussion at the hands of a number of geologists. In the majority of cases, however, the conclusions formed have been connected with certain fundamental assumptions concerning the validity of which there is at present profound skepticism. As these new doctrines are more or less intimately associated with new fundamental hypotheses, a test of the one is in a measure a test of the other; but a discussion of original postulates does not fall primarily within the province of this investigation. Therefore the discussion will proceed along the lines already indicated and in the order above mentioned.

Nature and extent of the sea.— In order to present the data upon which our conclusions concerning the nature and extent of the Jurassic sea are based it will be necessary to give a summary of the stratigraphical and faunal conditions of the present known Jurassic areas. In collecting this data I have consulted the writings of a long list of geologists who have labored in this particular geological field.[1] On the whole it may be said that the results obtained by these men are strikingly harmonious; so that no grave difficulty should be met in any attempted logical interpretation of the facts.

These Jurassic areas will be discussed in the order which follows: (1) The South Central Wyoming area; (2) the Southeastern Idaho area; (3) the Northern Uinta area; (4) the Southern Uinta area; (5) the Southern Utah area; (6) the Black Hills area; (7) the Montana area; (8) the Canadian area; (9) the Aleutian

[1] For references see following discussion.

area. Many of these terms have been used in a loose geographic sense since the object is to include under one name all of the minor localities belonging to one areal province. The numbers on the map[1] indicate the position of these areas.

THE SOUTH CENTRAL WYOMING AREA

The Freeze-Out Hills.[2]—The oldest rocks recognized in the Freeze-Out Hills are the Carboniferous. They occupy the center of the partly dissected anticline and are overlain by the Red Beds which are composed of sandstones and reddish arenaceous clays and marls inclosing here and there lenticular masses of gypsum or gypsiferous clays. These beds are seemingly devoid of fossils and are apparently conformable with the overlying Jurassic beds of unquestionable marine deposition. At a point on the Dyer Ranch the following stratigraphical conditions of the contact between the Red Beds and the Jura were noted in ascending order :[3]

1. Base, near top of the Red Beds, reddish clay, 2′+;
2. White, indurated sandstone, 4′;
3. Clay, light red, 5′;
4. White sandstone with a reddish tinge, 1′;
5. Light red clay, 2′;
6. White, slightly indurated sandstone, 6′;
7. Shale, reddish changing to purple, 4′;
8. White fissile arenaceous limestone, 6′;
9. Arenaceous clay of a dull red color, 10′;
10. White laminated arenaceous limestone containing fossils, 6′.

This last stratum contains a characteristic Jurassic type, *Pseudomonotis curta* Hall. This is the first or lowest known fossil bearing horizon of the Jura in this area. Any division line between the Red Beds and the Jura placed lower than this fossil bearing stratum would be an arbitrary one as there appears to be no unconformity to mark the separation. To the beds occurring above the fossiliferous horizon the term Jura-Trias is no

[1] See p. 245. [2] LOGAN: Kansas Uni. Quart., April 1900.

[3] Quoted from paper mentioned above.

longer applicable as they are unquestionably Jura. As the Red Beds represent the whole interval of time from the Carboniferous to the Jurassic so far as evidence to the contrary is concerned the term Jura-Trias alone is not applicable to them.

Continuing the section already begun we have for number

11. Arenaceous clay of a somewhat shaly nature, 6′. This layer contains near the central horizon a more highly arenaceous stratum of greenish color. It has scattered through it at different levels some rather large brown argillaceous concretions. The entire stratum seems to be unfossiliferous but it may contain *Belemnites densus* as it is often difficult to determine whether this fossil does, or does not, belong to the lower beds, since, on account of its abundance in the upper beds, it is usually scattered superficially throughout the full extent of the outcrop.

12. White sandy clay, 4′. No invertebrate fossils were found in this stratum but the remains of marine saurians belonging to the genera, *Ichthyosaurus* and *Plesiosaurus* occur in considerable abundance.

13. Purplish fossiliferous clay containing calcareous nodules, 20′. The most abundant fossil in this stratum is *Belemnites densus* which occurs distributed throughout the layer while the other fossils are confined chiefly to calcareous concretions. From these concretions the following forms were obtained: *Pinna kingi* Meek; *Cardioceras? cordiforme* M. & H.; *Belemnites densus* M. & H.; *Astericus pentacrinus* M. & H.; *Astarte packardi* White; *Pleuromya subcompressa* White; *Pseudomonotis curta* Hall; *Tancredia bulbosa* White; *Goniomya montanaensis* Meek; *Tancredia magna* Logan; *Lima lata* Logan; *Belemnites curta* Logan; *Cardinia wyomingensis* Logan and *Avicula beedei* Logan. This stratum contains also the remains of *Plesiosaurs* and *Ichthyosaurs*. It is the most abundantly fossiliferous of the entire series. It is also one of the most persistent beds, and is everywhere characterized by the great abundance of *Belemnites*.

14. Greenish colored sandstone separating into thin layers, 2′ to 4′. This stratum is very persistent, contains considerable calcareous matter, and is easily recognized on account of its

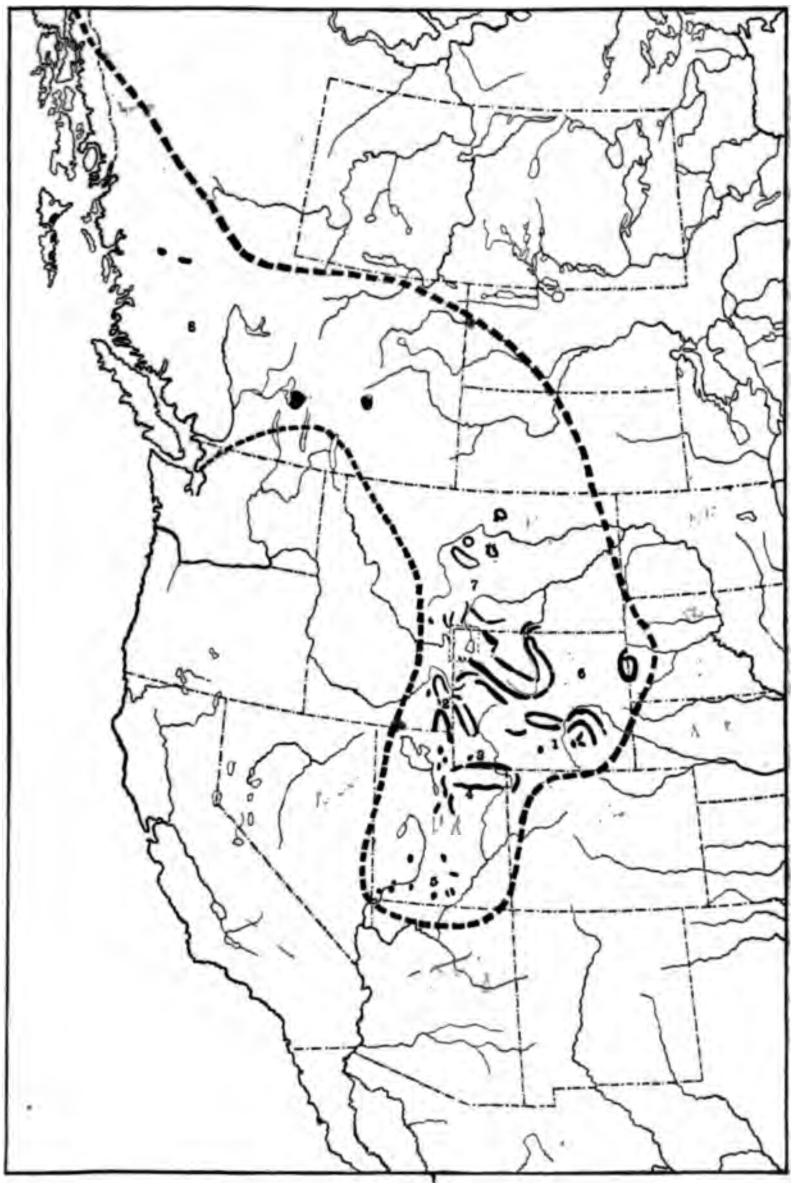

FIG. 1.—Map showing the distribution of the Jurassic formation in the interior.

uniformly greenish color. The following fossils occur in it: *Camptonectes bellistriatus* Meek; *Camptonectes extenuatus* M. & H.; *Gryphea calceola* var. *nebrascensis* M. & H.; *Ostrea strigilecula* White and *Ostrea densa* Logan.

15. Purplish clay containing considerable arenaceous inclusions, 40′. The clay contains in the upper part a thin strata of sandy limestone in which the following fossils were found: *Pentacrinus astericus* M. & H.; *Asterias dubium* White; *Pseudomonotis curta* Hall; *Avicula macronatus* M. & H.; and *Ostrea strigilecula* White.

Como beds.—The last stratum is the uppermost one, containing marine fossils and probably closes the Jura. The succeeding layer varies so much in thickness within short distances that it may represent the slightly eroded surface upon which the Como beds were deposited.

16. Fine-grained, grayish-white sandstone, 10′ to 125′. The above stratum varies much in thickness within short distances. At one point on the Dyer Ranch it has a thickness of 10′, while a few miles southeast of that point it reaches a thickness of 125′. The sandstone composing the layer is of nearly uniform color and texture. Its induration is only moderate, and it weathers into many grotesque forms. Cross-bedding is well exhibited by it in many localities.

17. Purple to greenish colored clay, 60′. This is apparently an unfossiliferous layer except in the uppermost horizon, where species of *Dinosaurs* belonging to the genera *Brontosaurus* and *Morosaurus* occur. This is the lowest fossiliferous horizon of the Como beds and the beds included between this horizon and the layer marked 15 may represent the transition from marine to non-marine conditions.

18. Sandstone, grayish to light brown, 10′ to 20′. The above sandstone presents some very interesting stratigraphical phenomena. It has at the base a layer of conglomerate about 2½′ thick. The conglomerate is composed of small argillaceous and silicious pebbles, and is not very coherent. Something like two feet of sandstone rest upon the conglomerate; the

bedding planes of the sandstone are oblique to the beds above and below. Succeeding the sandstone above is 6″ of sandstone in very thin layers, with lignitic seams along its horizontal but wavy bedding planes. The above is overlain by 4″ of conglomerate followed by 1′ of sandstone with oblique bedding planes. Overlying this layer is a thin layer of sandstone in which the bedding planes are horizontal. The remainder of the stratum is made up of sandstones with the thicknesses and bedding planes as follows: 1′ oblique; 3″ horizontal; 2′ oblique; and finally 3″ horizontal.

The beds furnished in one place the trunk of a large fossil tree and a large number of fossil cycads. Fragments of wood were found in a number of places, but cycads in only the one. Fragments of a hollow-boned *Dinosaur* were secured from one place in the horizon.

19. Drab-colored clay, 30′ to 40′. This stratum contains the remains of *Brontosaurus* and *Morosaurus*. Otherwise it appears to be unfossiliferous.

20. Fissile, brownish sandstone, 4′ to 5′. No fossils were found in this sandstone, and a most characteristic feature about it is its uniformly brown color. It seems to be moderately persistent, as it was noticed in many places in the hills.

21. Bluish-green clay, containing very small concretions, 30′. In the bone quarries of this horizon, which furnished species of *Brontosaurus*, *Morosaurus* and *Diplodocus* were found specimens of *Lioplacodes* (*Planorbis*) *veternus* Meek, and *Valvata leei* Logan. This is the lowest horizon at which any of these non-marine invertebrates were noticed. It is very probable that they will be found in the beds below as they indicate similar conditions of deposition.

22. Brown to bluish-gray arenaceous limestone, 8″ to 1′. This stratum contains the following non-marine invertebrate forms: *Unio knighti* Logan; *Unio willistoni* Logan; *Unio baileyi* Logan; *Valvata leei* Logan; and *Lioplacodes* (*Planorbis*) *veternus* Meek. Species of the same genera have been described by Meek from a similar stratum of limestone in the Black Hills.

As these occupy much the same stratigraphical position they are very likely of the same age. The *Lioplacodes* seems to be identical with that described by Meek in the Geology of the Upper Missouri.

23. Drab-colored clay, 70′. Species of the genera *Brontosaurus*, *Diplodocus*, *Morosaurus*, *Stegosaurus* and *Allosaurus* occur in this horizon. Portions of species of all these genera were found in one quarry by the Kansas University collecting party of which the writer was a member. The clay is of that quality usually designated as joint clay. It contains, in places, iron and argillaceous concretions of small size. The iron and sometimes the bones are covered with small selenite crystals.

24. Grayish-white sandstone, 50′. This layer forms a conspicuous capping for the hills, and is the highest remnant of the anticline. It breaks up into large blocks, which lie scattered along the slopes of the underlying softer beds. Its erosion and disintegration is accomplished chiefly by sapping. No fossils were found in this stratum" (Dakota ?).

The maximum thickness of the Jura for this locality does not at the most exceed 100 feet. All of the fossils are found in a vertical range of but little more than half that distance, and yet the fauna includes all the characteristic species of the interior Jurassic province. The beds are heterogeneous and indicate constantly varying conditions of sedimentation.

The entire section is given in its minutest details so that an idea of the general character of the Como beds may be obtained. In many localities this formation has been included in the Jura, although the Jura is wholly marine while on the other hand the Como is wholly fresh water. On the whole the marine beds are more calcareous but there is usually at least one thin bed of limestone in the Como. The lithological characters of the beds do not always stand out so clearly that the evidence of fossils is not required to separate the beds.

Como Lake.[1]—The stratigraphical conditions of the formation at Lake Como are not essentially different from those of the

[1] LOGAN : loc. cit.

Freeze-Outs. The beds have the same lithological characteristics, being composed of sandstones, arenaceous clays, marls and impure limestones. They rest on the Red Beds and are overlain by about the same thickness of the Como (Atlantasaurus) beds. The latter formation is capped by an apparent continuation of the same quartzitic layer which forms the surface stratum in the Freeze-Outs. From this area the following species have been determined by the writer and others: *Asterias dubium; Pentacrinus astericus; Belemnites densus; Cardioceras? cordiforme; Pseudomonotis curta; Camptonectes bellistriatus; Ostrea strigilecula; Ostrea comoensis; Pinna kingi; Tancredia inornata; Pleuromya subcompressa; Astarte packardi;* and *Goniomya montanaensis.*

Rawlins Peak.—The Jurassic at this point exhibits about the same thickness and lithological characters as that of the Como area. The beds contain the following forms: *Camptonectes bellistriatus; Belemnites densus; Astarte packardi; Pseudomonotis curta; Ostrea strigilecula;* and *Pentacrinus astericus.*

Sweetwater.—In the Sweetwater Drainage area Endlich[1] gives 300 feet as the thickness of the jura at that place and states that it contains a Gryphea and a Belemnites.

East of the Wind River Range according to the same writer[2] the Jura has a thickness of 200 or 220 feet and consists at the base of dark calcareous shales, covered by beds of dark blue limestones. These are followed by yellow shales and marls with intercalations of thin sandstone layers. Yellow, pink and greenish marls close the section. The fossils obtained are species of *Belemnites*, *Gryphea*, *Rhynchonella*, *Lingula*, *Modiola*, *Pecten*, and others.

THE SOUTHEASTERN IDAHO AREA

In this area St. John[3] places the thickness of the Jura at 2000 feet. Since, however, only the lowermost beds are fossiliferous it is probable that the Jura should be restricted to that

[1] Ann. Rep. U. S. Geol. Surv., Vol. XI, 1877, p. 108.

[2] *Ibid.* p. 87.

[3] Ann. Rep. U. S. Geol. Surv., Vol. XI, 1877, p. 495.

horizon. The beds consist here as elsewhere of alternating beds of sandstone, shales, and limestones.

In the Lincoln Basin the following Jurassic fossils were collected: *Ostrea strigilecula; Belemnites densus; Pentacrinus, Ostrea, Gryphea, Camptonectes*, and *Pseudomonotis*.

At Meridian Ridge Peale[1] found 150 feet of bluish and gray limestones; bluish laminated limestones and bluish argillaceous shales and slates followed by 100 feet of reddish sandstone and bluish limestone containing *Pentacrinus astericus; Ostrea strigilecula; Camptonectes bellistriatus* and other forms. This thickness of 250 feet doubtless represents a conservative average for the entire district.

On the John Day (Gray) River[2] the following fossils were collected: *Pentacrinus astericus; Belemnites densus; Camptonectes bellistriatus; Gryphea, Trigonia*, and *Pleuromya;* and from another outcrop, *Pentacrinus astericus; Ostrea strigilecula*, and *Tancredia sp.* An outcrop in the Sublette Range furnished *Pentacrinus astericus* and *Camptônectes bellistriatus.*

The Jura at Bear Lake Plateau[3] contains *Pseudomonotis curta* and other forms. The fossiliferous beds consist of 90 feet of gray limestone and 80 feet of bluish-gray limestone with bands of sandstone. This group rests on 150 feet of limestone which may also be Jura but there is no faunal evidence of its age.

On Bear River in Southwestern Wyoming Meek[4] gives the following section for the Jura: "Ferruginous sandstone, in thin layers, dipping northwest about 80° below horizon, 40 feet; bluish laminated clays with, at top (left or west side), a two-foot layer of sandstone containing fragments of shells not seen in a condition to be determined, 125 feet; Clays and sandstones, below (20 feet); gray and brown pebbly sandstone above (25 feet), 45 feet; brownish and bluish clays, with some beds of white, greenish, and brown sandstone, 115 feet." From the second layer the following fossils were obtained: *Belemnites*

[1] Ann. Rep. U. S. Geol. Surv., Vol. XI, 1877, p. 536.

[2] *Ibid.* p. 544. [3] *Ibid.* p. 585.

[4] Ann. Rept. U. S. Geol. Surv., Vol. VI, 1872, p. 451.

densus, Trigonia Quadrangularis, and *Pleuromya weberensis ?* This stratum of 125 feet is all of the section that can, with certainty, be assigned to the Jura, as the other layers are unfossiliferous.

The third and fourth layers correspond in character to the Como beds in other areas in Wyoming.

THE NORTHERN UINTA AREA

Flaming Gorge.[1]— In the Flaming Gorge the total thickness of the Jurassic is placed at 700 feet. Three hundred feet near the middle of the outcrop contains: *Camptonectes bellistriatus; Gryphea calceola; Pentacrinus astericus; Rynchonella gnathophora; Trigonia americana, Trigonia conradi; Ostrea strigilecula;* and *Belemnites densus.* In the absence of fossil evidence the portion of the outcrop lying above and below this horizon cannot with certainty be assigned to the Jura. Therefore it is possible that the three hundred feet represents the whole thickness of the Jura for this area.

South of Dead Man's Springs calcareous beds which are thought to represent the middle part of the Jura for that area contain: *Camptonectes bellistriatus; Myophoria lineata; Gryphea calceola;* and *Pentacrinus astericus.*

Vermillion Cliffs.[2]—From Vermillion Cliffs in Northwestern Colorado White determined the following Jurassic species: *Belemnites densus; Cardioceras cordiforme; Pentacrinus astericus; Rhynchonella gnathophora; Rhynchonella myrina; Ostrea strigilecula; Ostrea procumbens;* and *Modiola subimbricata.*

The limits of the Jurassic sea in a southeasterly direction do not appear to have been far from this point. Northwestern Colorado has up to this time been the only part of the state to which unquestionable Jura could be assigned.

On Sheep Creek a basal limestone yielded *Camptonectes bellistriatus; Myophoria lineata; Gryphea calceola; Pentacrinus astericus; Belemnites densus;* and specimens of *Ostrea*, *Trigonia*, and *Volsella*.

[1] KING: Geology of the 40th parallel, Vol. I, p. 290.

[2] WHITE: Geology of Northwest Colorado, U. S. Geol. Surv., Vol. XII, 1878.

THE SOUTHERN UINTA AREA

Ashley Creek.[1]—The thickness of the Jurassic beds on Ashley Creek is estimated to be about 750 feet. Of this thickness 50 feet are blue and drab colored shales and limestones carrying *Gryphea calceola, Pseudomonotis (Eumicrotis) curta* and *Belemnites densus.* This stratum corresponds to the more densely fossiliferous zone of other localities. As the vertical range of the fossils is not given it is difficult to say whether all of the 750 feet should be included in the Jura.

Near Peoria on the western end of the range a basal limestone contains *Pseudomonotis curta* and is followed by a group of shales and marls. No thicknesses are given for this area.

Wasatch Range.[2]—In Weber canyon of the Wasatch Range the Jurassic is estimated to have a total thickness of 1600 feet. The lower part which consists of yellow and bluish limestones and calcareous shales has a thickness of 600 feet. It contains the following fossils: *Cucullaea haguei; Pleuromya subcompressa; Myophoria lineata; Myophoria sp.* and *Volsella scalpra.* As the upper 1000 feet of arenaceous texture is unfossiliferous it is more than probable that it is not of Jurassic age. As the vertical range of the fossils is not given we have no means of ascertaining how much of the 600 feet may, also, belong to another period.

At the mouth of Thistle Creek in Spanish Fork Canyon the following fossils were found: *Lyosoma powelli, Camptonectes stygius* and *Pinna sp.*

THE SOUTHERN UTAH AREA

According to Dutton[3] the known Jura of Southern Utah has a thickness of from 200 to 400 feet. The formation consists of a series of calcareous and gypsiferous shales. The beds are distinctly fossiliferous and thin out toward the south, entirely disappearing in northern New Mexico and Arizona. A few fossils have been collected from a number of localities in the region.

[1] KING: Geology of the 40th Parallel, Vol. I, p. 292.

[2] KING: l. c. p. 293.

[3] Geology of the High Plateaus, Utah, p. 150.

From specimens collected on the Santa Clara River two miles below Gunlock White determined the following species: *Pentacrinus astericus* M. & H.; and *Trigonia sp.* Wh.; from near Kanara: *Pentacrinus astericus* M. & H.; *Camptonectes stygius* White; *Camptonectes bellistriatus* M. & H.; from the northern part of aquarius plateau; *Camptonectes platessiformis* White; *Trigonia montanaensis* Meek and *Gervillia sp.* White; from Potato Valley, Diamond Valley, and near Gunnison: *Pentacrinus astericus* M. & H.

From the geographic distribution of the Jura in this region it appears that the Jurassic sea did not extend far south of the southern boundary of Utah. It may be assumed also that its eastern as well as its western shore lines did not extend in this region much beyond the state boundaries. From this point the eastern shore line extends farther and farther east crossing the northwest corner of Colorado thence continuing toward the northeast and including the Black Hills area.

The thinning out of the beds toward the south may be due to the presence of a low land area at the south during this epoch. A high land area should give a thick shore deposit of a coarse, clastic nature. According to the above statements, however, the beds consist of calcareous and gypsiferous shales which indicate either a somewhat remote shoreline or a low bordering land area.

THE BLACK HILLS AREA [1]

The Jurassic formation forms one of the members in the rim of sedimentary rocks which encircles the crystalline area of the Black Hills. Here as in the central and southern areas the Jura rests upon the Red beds and is overlain by the Lower Cretaceous, the Como beds. Its thickness is in the neighborhood of 200 feet. It exhibits in general about the same lithological characters that are noticeable in the formation in the Southern Wyoming area. The beds consist of sandstones, arenaceous shales and marls, and thin beds of impure fissile limestone.

Whitfield[2] has determined the following species from this

[1] JENNEY: Nineteenth Ann. Rep. U. S. Geol. Surv., p. 593.

[2] Geology of the Black Hills, 1884.

area: *Asterias dubium* Whitf.; *Pentacrinus astericus* M. & H.; *Lingula brevirostris* M. & H.; *Rhynchonella myrina* M. & H.; *Ostrea strigilecula* White; *Gryphea calceola*, var. *nebrascensis* M. & H.; *Pecten newberryi* Whitf.; *Camptonectes bellistriatus* M.; *Camptonectes extenuatus* M. & H.; *Pseudomonotis curta* Hall; *Pseudomonotis orbiculata* Whitf.; *Avicula* (*Oxytoma*) *mucronata* M. & H.; *Gervillia recta* M.; *Grammatodon inornatus* M. & H.; *Mytilus whitei* Whitf.; *Volsella* (*Modiola*) *formosa* M. & H.; *Volsella pertenius* M. & H.; *Astarte fragilis* M. & H.; *Trapezium bellefourchensis* Whitf.; *Trapezium subequalis* Whitf.; *Pleuromya newtoni* Whitf.; *Tancredia inornata* M. & H.; *Tancredia corbuliformis* Whitf.; *Tancredia bulbosa* Whitf.; *Tancredia postica* Whitf; *Tancredia warrenana* M. & H.; *Dosina jurassica* Whitf.; *Psammobia? prematura* Whitf.; *Thracia? sublevis* M. & H.; *Neaera longirostra* Whitf.; *Saxicava jurassica* Whitf.; *Quenstedioceras* (*Cardioceras*) *cordiforme* M. & H.; and *Belemnites densus* M. & H.

In the Big Horn Basin region Eldridge[1] discusses the Jura as follows: "This, so far as the evidence obtained indicates, is, within the region under examination, wholly of marine origin. The thickness is between 400 and 600 feet, which is approximately maintained over the entire area of exposure. Shales constitute the mass of the formation in which from base to summit occur thin beds of sandstone and fossiliferous limestone of types characteristic of the Jura in the Rocky Mountain region. Gray is the predominating color of the shales, but throughout the formation red, purple, yellow, slate, and pink, in greater or less intensity, may be observed. At a number of localities a considerable amount of siliceous matter appears, in occurrence suggesting the action of hot waters.

"The sandstones are of slight importance. They are chiefly gray with a slight greenish tint. The lower beds, however, are red, shaly and transitional from the Trias, while near the summit are two of greater thickness, which, but for their tint and the overlying typical Jura shales, might be confounded with the Dakota.

[1] Bull. U. S. Geol. Surv. No. 119.

"The limestones are nearly all fossiliferous, and of the drab color peculiar to the Jura in the west. In thickness they vary from a few inches to 15 feet. Three or four in the lower 100 feet and one or two in the upper third of the formation are especially prominent."

The formation is said to be overlain by the Dakota sandstone. If this so-called Dakota sandstone is at the same horizon that it is in the Freeze-Out Hills, and it seems from the description very probable that it is, then the Jura so-called must include the Como beds. The description of the upper part of the formation fits the Como, while the lower part with its fossiliferous limestones is very characteristic of the Jura both north and south of this area. The Como or its stratigraphic equivalent is recognized both north and south of this region and there appears no good reason for its absence in this area.

THE MONTANA AREA

Castle Mountain.[1]—The Jurassic formation in this area is less than one half the average thickness for the interior. Its maximum thickness is only ninety feet. The formation consists of a basal sandstone overlain by a dense white limestone. The limestone layer is highly fossiliferous and contains the following well-known Jurassic forms: *Astarte packardi; Trigonia montanaensis; Pinna kingi; Pholadomya kingi; Ostrea sp.; Camptonectes extenuatus; and Gervillia montanaensis.*

The Jura of this locality rests upon upon the Carboniferous and the Red Beds are not represented. It is the belief of the writers that the beds are wanting altogether in Montana, or at least but sparingly represented.

Little Rocky Mountains.[2]—The total thickness of the Jura for this region is placed at 100 feet. The beds consist of shaly gray limestones which change to impure, marly shales and argillaceous limestones. They rest on limestones of Carboniferous age and the Red Beds are again absent.

[1] WEED and PIRSSON, Bull. 139, U. S. Geol. Surv., 1896.

[2] WEED and PIRSSON, JOUR. GEOL., Vol. IV, 1896.

The Jurassic limestones contain the following species: *Astarte meeki; Belemnites densus; Pleuromya subcompressa; Gryphea calceola*, var. *nebrascensis;* and a fragment of an undetermined Ammonite.

This is one of the most northerly areas from which Jura has been recorded for Montana. If the formation is present in the Bear Paw Mountains which lie to the northwest of this area it has not been differentiated.

Three Forks.[1]—The Jura has a thickness in this area of from 300 to 400 feet. The lower beds rest on a basal quartzite and consist of argillaceous limestones which carry characteristic Jurassic fossils. The middle and upper beds are more arenaceous than the lower beds and are non-fossiliferous. Under such conditions it is very questionable whether they should be assigned to the Jura. It is very probable that the thickness of the Jura in this area conforms more nearly to that assigned to it in other areas of Montana.

Livingston.[2]—The Jurassic formation of the Livingston area has a thickness estimated at 400 feet. It consists at the base of a massive, cross-bedded, ripple-marked sandstone. This sandstone is overlain by a layer of impure fossiliferous limestone containing *Pleuromya subcompressa* M. The limestone is followed by a bed of arenaceous limestones containing shell fragments. Since the lower layer is non-fossiliferous it may or may not represent a part of the Jura, but there is the possibility of an overestimation of thickness here as well as in the Three Forks area.

Although the thicknesses given for the Three Forks and Livingston area are not extremely large, yet they are nearly double that given for the other Montana areas. But as has been pointed out, this lack of harmony may be due to the inclusion of beds belonging to other formations. If the faunal relations are not carefully worked out in connection with the stratigraphy errors are likely to occur either in the direction of the overlying

[1] PEALE, U. S. Geol. Surv., Three Forks Folio, 1896.

[2] IDDINGS and WEED, U. S. Geol. Surv., Livingston Folio, 1894.

or the underlying beds. For the Jura in many localities, so far as physical characters are concerned, grades almost imperceptively into the Red Beds below and the Como above.

Judith Mountains.[1]—Weed and Pirsson give the following section as representing the Jura in the Judith Mountains. The base is separated from the Carboniferous by a sheet of porphyry.

		Feet.
1.	Limestone, dark gray, laminated, and shaly	10
2.	Limestone, blue to gray in color, hard in texture, and carrying Ostreæ in 3 to 5-foot beds, separated by thinner platy beds	12
3.	No exposure	25
4.	Shaly, argillaceous, impure limestone, dove colored, weathering buff on joint faces and of typical Jurassic aspect	5
5.	Shaly beds, seldom exposed, carrying oolitic limestone. Green or sandy limestone of drab color	15
6.	Rough weathering limestone, fine grained, cross-bedded and fissile, carrying fossils	5
7.	Sandy limestone like that above, but irregularly bedded and resembling sandstone; granular and saccharoidal in texture, carries shell fragments	4
8.	Irregularly platy, earthy-brown, gray limestone carrying shell remains of *Gryphea* and *Ostrea*, weathering dark brown, rarely granular	6
9.	Marly shales and limestone, dove colored, carrying fossils noted in following pages, seldom exposed, *Gryphea* most abundant here	30
10.	No exposure, but débris of sandstone	60
11.	Ellis sandstone, variable, buff, platy sand rock; pink blotched at base with occasional shells; cross-bedded purple-brown outcrop. It is at the top a limestone full of black and white quartz sand grains and forms a dark brown ridge	12

This section gives the total thickness of the Jura for this region at 184 feet, which is nearly double that of the Little Rocky and Castle Mountain areas.

The fossils collected from the horizon mentioned above are: *Ostrea strigilecula* White; *Gryphea calceola* var. *nebrascensis* M. & H.; *Modiola subimbricata* M.; *Cucullaea haguei* M.; *Pleuromya subcompressa* M.

[1] WEED and PIRSSON, Eighteenth Ann. Rept., U. S. Geol. Surv., III, p. 445.

Yellowstone Park.[1]—The thickness of the formation for this area is placed at 200 feet. It consists of sandstones, marls, limestones, and clays, and contains, according to Stanton,[2] the following species: *Pentacrinus astericus* M. & H.; *Rhynchonella myrina* Hall & Whitf.; *Rynchonella gnathophora* M.; *Ostrea strigilecula* White; *Ostrea engelmani* M.; *Gryphea planoconvexa* Whitf.; *Gryphea calceola* var. *nebrascensis* M. & H.; *Lima cinnabarensis* Stan.; *Camptonectes bellistriatus* M.; *Camptonectes bellistriatus* var. *distans* Stanton; *Camptonectes pertenuistriatus* Hall & Whitf.; *Camptonectes platessiformis* White; *Avicula* (*Oxytoma*) *Wyomingensis* Stan.; *Pseudomonotis Curta* (Hall)?; *Gervillia montanaensis* M.; *Gervillia* sp. Stan.; *Modiola subimbricata* Meek; *Pinna kingi* M.; *Cucullaea haguei* M.; *Trigonia americana* M.; *Trigonia elegantissima* M.; *Trigonia montanaensis* M.; *Astarte meeki* Stan.; *Astarte* sp. Stanton; *Tancredia? knowltoni* Stan.; *Protocardia shumardi* M. & H.; *Cyprina? Cinnabarensis* Stanton; *Cyprina? iddingsi* Stanton; *Cypricardia? haguei* Stanton; *Pholadomya kingi* M.; *Pholadomya inaequiplicata* Stan.; *Homomya gallatinensis* Stan.; *Pleuromya subcompressa* M.; *Thracia weedi* Stanton; *Thracia? montanaensis* (Meek)?; *Anatina* (*Cercomya*) *punctata* Stan.; *Anatina* (*Cercomya*) sp. Stan.; *Neritina wyomingensis* Stan.; *Lyosoma powelli* White; *Turitella* sp. Stan.; *Natica* sp. Stan.; *Oppelia?* sp. Stan.; *Perispinctes* sp. Stan.; and *Belemnites densus* Meek and Hayden.

THE CANADIAN AREA

In the Queen Charlotte Islands Whiteaves[3] noted the occurrence of the following species, which are common to the Jura of the Interior: *Pleuromya subcompressa* Mk.; *Astarte packardi* White; *Avicula* (*Oxytoma*) *mucronata* Mk.; *Gryphea calceola* var. *nebrascensis* M. & H.; *Lyosoma powelli* White; *Belemnites densus* M. & H.; *Belemnites skidgatensis* Whiteav.; *Grammatodon inornatus* Whiteav.; *Modiola subimbricata* Mk.; and *Camptonectes extenuatus* Mk.

Although Whiteaves recognized the interior affinity of these forms, he was inclined to put both groups into the Cretaceous

[1] U. S. Geol. Surv., Yellowstone Park Folio, 1896.

[2] U. S. Geol. Surv., Yellowstone Park Monograph, XXXII, p. 601, 1899.

[3] Geol. Surv., Canada, Mesozoic Fossils, Vol. I.

rather than the Jura. But the Jurassic age of these beds is now sufficiently well established not to require further discussion.

Not only is this fauna represented in the islands just mentioned, but it occurs also on the continent at some considerable distance inland. From fossils collected by G. M. Dawson on the Iltasyouco River in British Columbia about Parallel 53° and Longitude 126° West, Whiteaves[1] recognized the following species: *Pleuromya subcompressa* Mk.; *Pleuromya lævigata* Whiteav.; *Astarte packardi* White; *Trigonia dawsoni* Whiteav.; *Modiola formosa* M. & H.; *Gervillea montanaensis* Mk.; *Gryphea calceola* var. *nebrascensis* M. & H.; *Grammatodon inornatus* Whiteav.; *Oleostephanus loganianus* Whiteav.

These fossils were found in the felsites and porphyrites of the metamorphic rocks lying east of the Coast Range. They contain species common to both the Queen Charlotte and the Interior faunas.

From fossils collected by G. M. Dawson at Nicola Lake in British Columbia Hyatt[2] determined the Jurassic age of certain beds in that region lying above the Triassic. The fossils collected are: *Rhynchonella gnathophoria?*; *Pecten acutiplicatus* Gabb; *Entolium* sp. Hyatt; *Lima parva* Hyatt.

Just north of Parallel 51°, near the east end of Devil's Lake, which is situated on the eastern border of the Front Range of the Rockies, McConnell[3] found an outlier of Jurassic which contained the following fossils: *Avicula* (*Oxytoma*) *mucronata*; *Trigonia intermedia*; *Trigonarca tumida*; *Terebratula*, *Ostrea*, *Camptonectes*, *Lima*, *Cyprina*, *Ammonites*, and *Belemnites*. This locality serves as a connecting link between the Montana area and the localities to the west, as it is situated midway between the two. The above-named group of fossils contains one species and a number of genera common to the Interior and the Pacific Coast deposits.

[1] Loc. cit.

[2] Rept. of Geol. Surv., Canada, 1894, p. 51.

[3] Rept. of Geol. Surv. Canada, 1896, p. 17d.

THE ALEUTIAN AREA

Grewingk[1] was the first to announce the occurrence of beds of Jurassic age in Alaska. These beds were discovered at different places along the Alaskan Peninsula and the Aleutian Islands. From the distribution of these beds as mapped by Grewingk the Alaskan Peninsula and the Aleutian Islands must have been under water during Jurassic times.

In 1872 Eichwald[2] described an assemblage of fossils collected from these same beds and correlated them with the Northern Russia beds of the same age, but put both formations in the Lower Cretaceous. Some fossils were collected from the same region by Dall in 1883. These forms were described by White,[3] who after making a study of them and comparing them with Eichwald's descriptions, decided that the latter was wrong in his assignment of the beds to the Cretaceous. He found them to be closely allied to the Jurassic of Northern Russia. One species, *Aucella concentrica* Fisher, he considers either identical or only a variety of the Eurasian Jurassic form of that name.

Hyatt,[4] in speaking of these deposits, says: "The fauna of the Black Hills, acknowledged to be Jurassic by everyone but Whiteaves, is in part apparently synchronous with that of the Aleutian Islands and Alaska, as described by Eichwald and Grewingk."

The position of these beds and the relation of the fauna with the northern Eurasian fauna points clearly to an Arctic-Pacific connection by way of the Bering waters during this epoch. Moreover we now have an almost continuous faunal record extending from Alaska to southern Utah.

Conclusions.—An examination of the above sections will show that the thickness of the Jura in the interior is not very great. An average of ten localities gives a thickness of but little over

[1] Russian Kaiserl. Mineral Gesell., 1848–9.

[2] Geognostisch-Paleontologische Bemerkungen über die Halbinsel Mangischlak und die Aleutschen Insel.

[3] Bull. U. S. Geol. Surv. No. 4, 1884.

[4] Bull. Geol. Soc. Am., Vol. V, 1894, p. 409.

two hundred feet. In fourteen localities the thickness is under four hundred feet. These localities are scattered throughout the length and breadth of the interior province. In all the areas for which greater thicknesses have been recorded there are none in which the entire thickness could, without question, be assigned to the Jura.

The lithological character of the beds is much the same for all areas. The formation consists everywhere of essentially the same group of arenaceous clays, shaly marls, impure limestones and sandstones. The order of succession of the beds implies ever changing conditions of sedimentation. Thin beds of sandstone are overlain by thin beds of fossilferous clays, marls, or limestones; and these in turn are followed by another similar group.

The absence of any considerable thickness of limestone over a large area indicates that for no great period of time were the waters of the sea entirely free from clastic sediments. The presence of cross-bedded sandstone and ripple-marked layers at different horizons, the almost universal presence of *Ostrea* and other shallow water forms, together with the stratigraphic and lithologic characters just mentioned prove that the waters of the sea were not of great depth; that the sea was not of the abysmal type. It was not a sea comparable in depth to the Mediterranean but was a shallow epicontinental sea. From the geographic distribution of the known Jurassic the outlines of this sea were as indiçated on the map[1] accompanying this paper.

From the character and extent of the sea it may be assumed that no extensive epeirogenic movement was necessary for its inauguration, providing the antecedent topographic conditions were favorable. In the northern part of the area there is evidence that a considerable period of erosion preceded the Jura, as the Red Beds are absent and the Jura rests on the Carboniferous. This period of erosion may have been sufficient to reduce the land area to approximate base level in which case a very slight warping would have been sufficient to let the waters of this

[1] See p. 245.

shallow sea in upon the continent. A very slight increase in the capacity of the ocean basin would suffice to draw the water off the continent at the close of the period. The increase in the capacity of the ocean may have been accomplished by a slight settling of the oceanic segment. The withdrawal of the waters of the epicontinental sea was doubtless the initial step in the movement which ended in the elevation of the Sierra Nevada Mountains; for the withdrawal took place at the close of the Oxfordian stage or during the Corallian and according to Diller[1] the orogenic movement which produced the Sierra Nevada and Klamath Mountains took place at the close of the Corallian. If these interpretations be logical ones we may assume that it required little or no bodily movement of the continent to produce either the inauguration of the Jurassic sea or its withdrawal from the continent. It may be asserted further that there is nothing connected with its history which is inimical to the doctrine that the continent had in general its present outline during Jurassic times and that the waters of the submerged portions were of an epicontinental nature.

The writer's study of the faunal conditions in the field has led him to the opinion that only one fauna is to be recognized in the Jurassic deposits of the interior province. A comparison of the fossils collected from the different areas just discussed serves to strengthen the opinion. Everywhere the formation is characterized by about the same group of fossils, of which the more characteristic ones are: *Pentacrinus astericus*, *Belemnites densus*, *Camptonectes bellistriatus*, *Pseudomonotis curta* and *Cardioceras cordiforme*. These forms all existed contemporaneously.

Stanton[2] discusses the view expressed by Hyatt[3] that more than one Jurassic fauna may be represented in the Interior and arrived at the following conclusion: "the stratigraphic relations and the geographic distribution of the marine Jurassic of the Rocky Mountain region are in favor of the idea that all of these deposits were made contemporaneously in a single sea."

[1] Bull. Geol. Soc. Am. Vol. IV, p. 228.

[2] U. S. Geol. Surv. Yellowstone Park Monograph XXXII, 1899, pp. 602–604.

[3] Bull. Geol. Soc. Am. Vol. III, 1892, pp. 409–410.

This fauna according to Hyatt belongs to the Oxfordian stage of the Upper Jura or Malm. In the Taylorville series of California he recognized the Callovian, the Oxfordian and the Corallian stages of the Upper Jura. But as has been stated above none but the middle stage has been recognized in the Interior.

Relation of the interior fauna to the northern eurasian fauna.—The discovery of beds of Jurassic age in the interior was first announced by Meek[1] in 1858. In correlating these beds with the Jura of the Old World he says: "The organic remains found in these series present, both individually and as a group, very close affinities to those in the Jurassic epoch in the Old World; so close indeed, that in some instances, after the most careful comparisons with figures and descriptions, we are left in doubt whether they should be regarded as distinct species, or as varieties of well-known European Jurassic forms. Among those so closely allied to foreign Jurassic species may be mentioned an Ammonite we have described under the name of *Ammonites cordiformis* which we now regard as probably identical with *Ammonites cordatus* of Sowerby; a *Gryphea* we have been only able to distinguish as a variety from *G. calceola* Quenstedt; a *Pecten*, scarcely distinguishable from *Pecten lens* Sowerby; a *Modiola*, very closely allied to *M. cancellata*, of Goldfuss; a *Belemnite*, agreeing very well with *B. excentricus*."

Since the publication of the above statements by Meek the paleontology of the European Jura has been more completely worked out and some of the faunas, particularly that of northern Russia, are found to have still closer affinities to the American interior fauna. The Jurassic faunas of America have also received many additions at the hands of the American paleontologists Gabb, Hyatt, Meek, Smith, Stanton, White, Whiteaves, and Whitfield. All of these studies have tended to strengthen the opinion just expressed.

The following comparison of forms which are so closely allied as to deserve, in many cases, to be called varieties of the same species will serve to show the close affinity of the interior

[1] Geological Report of the Exploration of the Yellowstone and Missouri Rivers.

American fauna to the fauna of northern Eurasia: *Belemnites panderanus* d'Orb. and *Belemnites densus* Mk.; *Astarte duboisianus* d'Orb. and *Astarte pakardi* White; *Avicula volgensis* d'O. and *Avicula mucronata* Mk.; *Pentacrinus scalaris* Goldf. and *Pentacrinus astericus* M. & H.; *Goniomya dubois* d'Orb. and *Goniomya montanaensis* Mk.; *Gryphea calceola*, Quen. and *Gryphea caceola* var. *nebrascensis* Mk.; *Cardioceras cordatus* Sow. and *Cardioceras cordiforme* Mk. The faunas taken as a whole exhibit the close relationship in a much more forcible manner than the comparison of a few species.

This northern Eurasian, or *Cardioceras* fauna is thought to have had its origin on the northern shores of the Eurasian continent, and to have migrated from there to American waters. This assumption is based on the sudden appearance of the fauna in America and its close affinities with older Eurasian faunas. The present geographic distribution of the fauna indicates a northern connection.

A later Jurassic fauna, the *Aucella* fauna, probably had its origin in the north and migrated to Pacific waters. This fauna, however, did not reach the interior province of America as the waters of the epicontinental sea had been withdrawn before its appearance. This later migration extended along the Pacific coast as far south as Mexico.

Both of the faunas just mentioned belong to the Upper Jura, but the Lias and Middle Jura are also represented in the Californian province. The Upper Jura, however, represents the maximum encroachment of the ocean on the American continent as well as on the Eurasian continent. It also marks the maximum expansion of marine life, induced doubtless by increased feeding grounds.

Connection of the sea with the ocean.—The question as to where the interior sea had its connection, or connections, with the ocean is important in estimating the extent of the submergence, That the sea had a Pacific Ocean connection there seems no longer room for doubt. The occurrence in the Queen Charlotte fauna of so many species common to the interior places the

question beyond controversy. That there was communication between the Arctic and the Pacific is supported by the presence of Arctic species in the Pacific fauna. From the distribution of the Jurassic sediments as given in the preceding pages it may be asserted with a measurable degree of confidence that the connection between these two bodies of water was during Jurassic times as it is today by way of the Bering waters. As the presence of Jurassic deposits on the Alaskan Peninsula and the Aleutian Islands testify to the submergence of those areas, it may be assumed that communication between the two oceans was somewhat freer than at present.

The question which is now brought to mind is whether the interior sea had any other connection with the ocean. The character of the fauna excludes any hypothesis favoring a southern connection either with the Gulf of Mexico or the Pacific. If there had been such a connection a southern facies would be expressed in its fauna. Such evidence is entirely absent. The evidence against any other Arctic connection is largely negative, but as such is measurably strong. The investigations of American and Canadian geologists have failed to bring to light any Jurassic deposits in the North aside from those already described, although approximately the whole area where we should expect to find them has been gone over.

McConnell,[1] who made geological investigations in Athabasca and along the Finlay and Porcupine Rivers, found Cretaceous beds resting on Devonian and Carboniferous strata. The interval of time which elapsed between the Carboniferous and the Lower Cretaceous is not represented in this region.

Spurr[2] found the same conditions to obtain for the Upper Yukon region of Alaska and the neighboring British territory. The Lower Cretaceous rests on Devonian or Carboniferous rocks. As before stated this evidence is merely negative. Jurassic rocks may have been deposited and afterwards cut away. But,

[1] Geol. Survey of Canada, Vols. V and VII.

[2] Geol. of the Yukon Gold District, U. S. Geol. Surv., Seventeenth Ann. Rept., 1897.

in that case, we should expect to find remnants of the former beds unless it be assumed that a long interval of time preceded the deposition of the Lower Cretaceous. Paleontologic and stratigraphic evidence is not in harmony with this assumption. The Lower Cretaceous beds of California which are but slightly unconformable with the Upper Jurassic, having a closely related fauna, are correlated with the Lower Cretaceous of the region under discussion.[1]

In many places in the interior region the Lower Cretaceous rests conformably on the Jurassic. This fact has been fully brought out in the preceding pages. It cannot be affirmed that the interior sea first had its connection with the Arctic and then gradually spread its waters farther and farther west until it united with the Pacific. For if this were true we should find in the interior first a fauna composed wholly of northern species, followed later by a fauna containing both Arctic and Pacific types. But no such conditions find expression in the faunal relations of the interior. Only one fauna exists in the interior.

There exists at present no evidence which will support the view held by Neumayr,[2] that the whole of Alaska and all of that portion of British America lying north of the interior Jurassic area of the United States was submerged during this epoch. All that can be asserted positively is that the Aleutian Islands and Alaskan Peninsula, in part at least, a narrow margin along the Alaskan coast and a wider area in California and Mexico was under water, while an arm of the Pacific extended in upon the continent from the region of the Queen Charlotte Islands.[3]

Lack of communication between the provinces.—The Jura of California and Nevada contains a fauna which is very different from that of the interior, although the faunas are contemporaneous. To explain the difference between the two faunas Neumayr assumed that that they belonged to two distinct climatic provinces. He assumed that the interior fauna was a Boreal fauna

[1] Spurr, l. c., p. 183.

[2] See map p. 267, copied from Erdgeschichte, p. 336.

[3] See map p. 245.

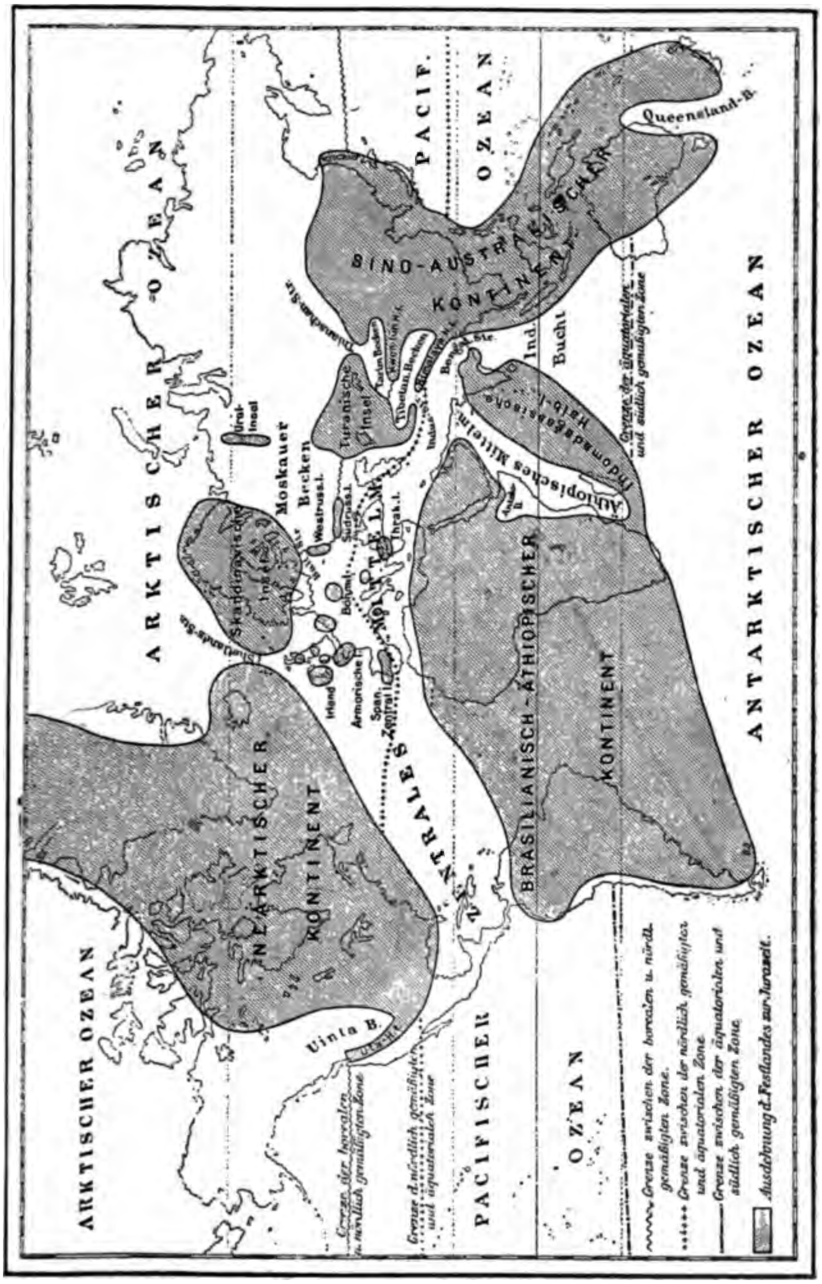
ARKTISCHER OZEAN
ARKTISCHER OZEAN
PACIF. OZEAN
SINO-AUSTRALISCHER KONTINENT
Queensland-B.
Ind. Bucht
Turanische Insel
Ural-Insel
Moskauer Becken
Skandinavische Insel
Indomadagassische Halb-I.
Äthiopisches Mittelm.
BRASILIANISCH-ÄTHIOPISCHER KONTINENT
NEARKTISCHER KONTINENT
Uinta B.
PACIFISCHER OZEAN
ANTARKTISCHER OZEAN
Grenze zwischen der borealen u. nördl. gemäßigten Zone.
Grenze zwischen der nördlich gemäßigten und äquatorialen Zone.
Grenze zwischen der äquatorialen und südlich gemäßigten Zone.
Ausdehnung d. Festlandes zur Jurazeit.

FIG. 2.

which lived in an arm of the Arctic Ocean, and that the Californian fauna belonged to another climatic province, the north temperate.

In a recent discussion of the subject Ortman[1] has shown very conclusively that the faunal differences of Jurassic times, so far as the Eurasian continent is concerned, were not due to climatic zones. The distribution of the interior or Cardioceras fauna favors this view for the North American continent, The Cardioceras fauna is found distributed through a range of latitude extending from 37° to 80° north. Its southernmost extension is not as placed by Neumayr in the neighborhood of 46°, but is at least as far south as 37°, and is found in approximately the same latitude as the Californian province. Moreover, the later (for the American region) Jurassic fauna, the Aucella, has been reported from Mexico.[2] The Aucella fauna also had its origin in northern Eurasian waters. Its geographic range was from 80° north to 25° north. This means an extension of Neumayr's Boreal province to within 25° degrees of the equator! The great geographical range of this fauna indicates that there was little or no climatic restriction to its migration. In so far as the evidence can be deduced from the geographic distribution of the American Jurassic faunas the climate of the period may be said to have been more uniform than it is today.

The above facts are perhaps sufficient to show the weakness of the climatic-zone hypothesis. It now remains to suggest an alternative line of investigation. In seeking for the causes for the want of communication between the provinces it may be possible to draw some analogy from the faunal and topographic conditions as they exist today on the Pacific coast. There are at present on the Pacific coast, according to Fischer,[3] two faunal provinces, the Aleutian, corresponding in position to the Queen Charlotte of Jurassic times, and the Californian, corresponding to the Jurassic province of the same name. The line

[1] Am. Jour. Sci. Vol. I, 1896, p. 257.

[2] Nitikin, Neus Jahrb. Min. Geol. Pal., 1890, II, p. 273.

[3] Manuel Conchologie.

separating these two provinces is placed in the vicinity of Vancouver Island. The faunal interrelations of these two provinces are as follows: Of seventy-eight genera occurring in the two provinces nine are common to both ; of one hundred and four species six are common to both ; and of ten circumpolar species which have reached Vancouver Island and Puget Sound only four occur in California, and but one in Lower California. From these conditions it will be seen that communication between the two provinces is almost, if not quite, as thoroughly prohibited now as it was during Jurassic times. The question which now arises is what restricts communication between the two provinces at present? It cannot be said to be due to climate alone, for why in that case should the circumpolar species be found so far south? And why should they all be found in Puget Sound and not be found farther south? This seems to be an exception to the general rule that the climatic provinces of the present time are connected by transition zones. For the line of demarcation is moderately sharp.

Aside from the matter of climate there are two physiographic conditions which may be operative. The first of these lies in the extreme narrowness of the sumerged shelf lying to the north and west of Puget Sound. This shelf teeming with organisms already well established offers small inducement to migratory forms. And only the more hardy forms would be likely to survive the struggle for existence under such circumstances as are here postulated. Thus the change of species from one province to the other is necessarily slow.

There are good reasons for believing that throughout the Mesozoic era these topographic conditions of the Puget Sound region were much as they are at present. During the Horsetown epoch the Pacific shoreline, although it lay a considerable distance east of the present shoreline in California and Oregon, very closely approximated it in the Puget Sound area. The Chico also had a very restricted epicontinental area at that point as the Chico shoreline extended only to the eastern coast of Puget Sound. In California and Oregon, however, its eastward

extension was far beyond that of the Horsetown.[1] The Jurassic beds do not occur in the Puget Sound region, and as they underlie the Horsetown elswhere, it is evident that the Jurassic shoreline at this point must have been at least as far west as the present shoreline.

A second cause for the lack of communication between the two provinces may lie in the position of the ocean currents. The Californian currents coming from the west along a line lying between the Queen Charlotte Islands and the island of Vancouver turns south at some notable distance from the coast, and after passing Vancouver bears toward the coast and flows on along the Californian province. The North Pacific current which flows east closely parallel to the Californian bears northward before reaching the Queen Charlotte Islands. Neither of these currents, since they do not cross the line separating the two provinces, is effective in establishing communication by carrying embryonic or larval forms which might under different circumstances be brought within their reach. This same distribution of ocean currents probably held during Jurassic times, as in general, the large land masses in this region, at least, had their present distribution.

The attractive feeding ground furnished by the epicontinental sea doubtless exerted its influence to prevent southern migration. When later the waters were drawn off the continent the accumulation of the great numbers of organisms on the coast may have been sufficient to force the migration southward. Or perhaps the interval of time was sufficiently long for some of these northern species to have forced their way into the Californian province during later Jurassic time. In either case we would have in the Upper Jurassic faunas of California a northern element, and this seems a well-established fact. Nevertheless, since this Upper Jurassic fauna has been reported from Mexico it is evident that communication was freer between the two provinces after the withdrawal of the waters of the epicontinental sea. And it is very likely that the movement which caused

[1] See map p. 271.

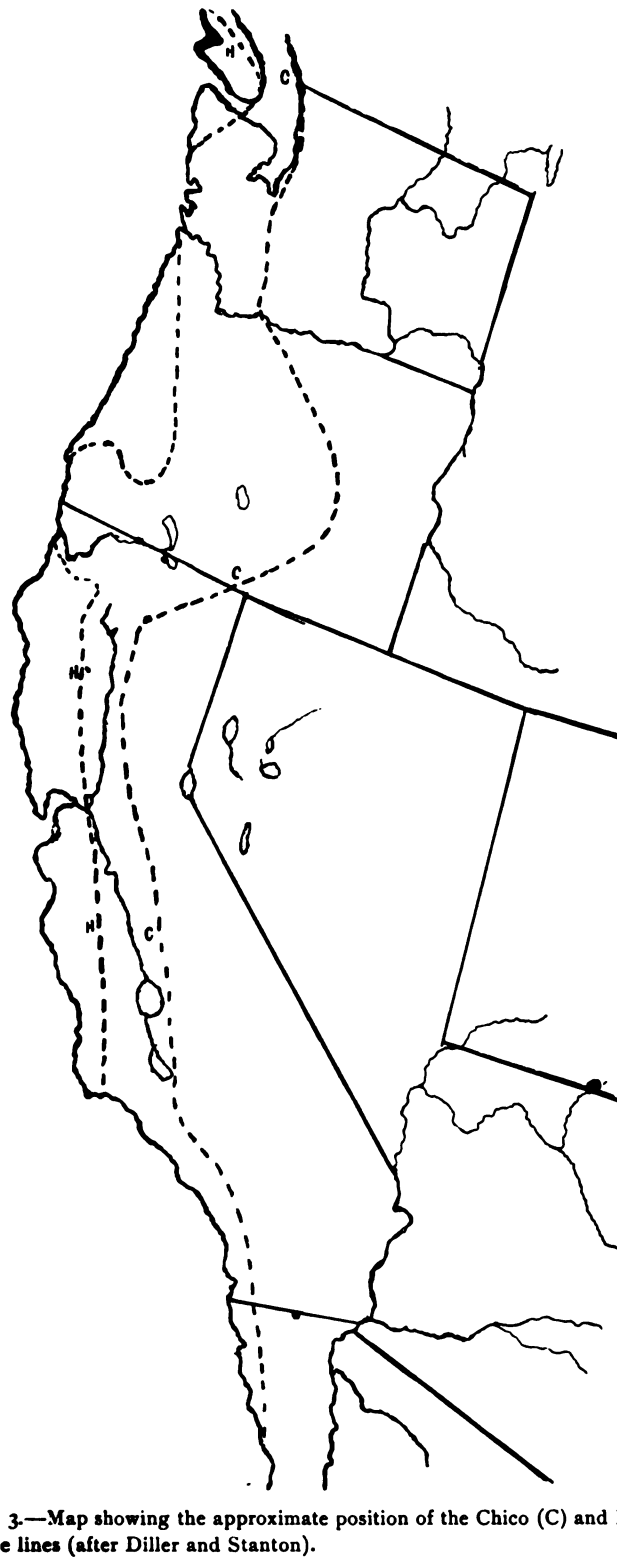

Fig. 3.—Map showing the approximate position of the Chico (C) and Horsetown (H) Shore lines (after Diller and Stanton).

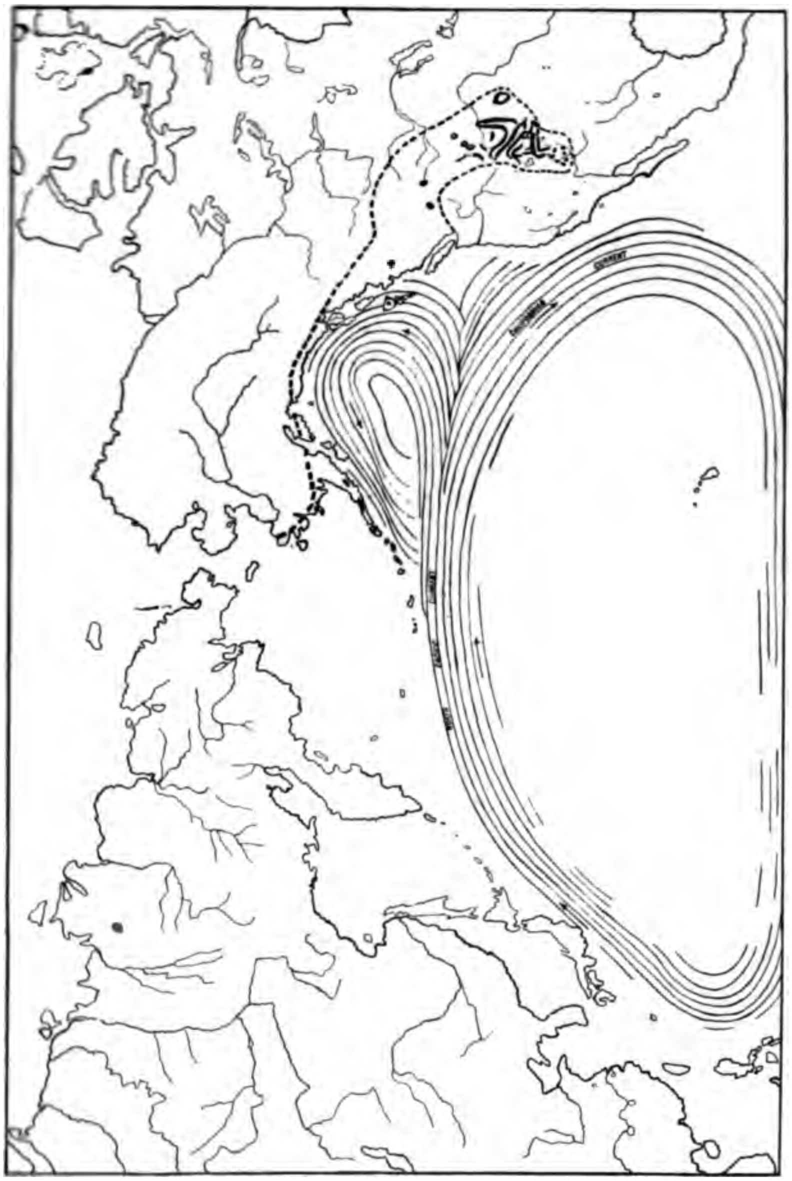

FIG. 4.—Map showing the position of the North Pacific Currents and the approximate outline of the Jurassic Sea.

the withdrawal also slightly depressed the barrier between the provinces.

Final conclusions.—It now remains to state briefly, in review, the conclusions to which the lines of investigation have led. They are as follows: 1. The Jurassic formation of the interior province of North America was not deposited in a body of water of even moderate oceanic depth, but in a shallow epicontinental sea.

2. This sea had but one connection with the ocean and that connection was with the North Pacific in the Queen Charlotte Island region; in general the outlines of the sea were as indicated on the map accompanying this article.

3. There was a connection, during this epoch, between the Arctic and Pacific by way of the Bering waters, and by this means circumpolar and Pacific faunal communication was established.

4. The Jurassic deposits of the interior contain but one fauna and if more than one period of time is represented it is not indicated by a change in the fauna.

5. The fauna of the interior is closely allied to the Cardioceras fauna of northern Eurasia.

6. Physiographic rather than climatic condition restricted communication between the Californian and interior provinces.

7. Nothing connected with the history of this Jurassic sea or its faunal relations is inimical to the view that during this epoch the North American continent had, in general, its present outline.

8. The geographic distribution of land and water, as postulated by Neumayr for this period, is not supported by the facts, in so far as the North American Jura is concerned.

W. N. LOGAN.

EDITORIAL

GEOLOGISTS heartily participate in the satisfaction which astronomers justly feel over the great mass of accurate data which favorable conditions and their own zeal and skill enabled them to gather from the recent solar eclipse. Geologists offer their cordial felicitations not only as fellow scientists rejoicing in the common advancement of science for its own sake, and for its influence on the world, but because they are themselves concerned in the solution of the solar problems. Especially are they interested in those questions of the sun's constitution and internal activities which bear upon his sources of heat, present, past, and future; for these vitally touch the limitations of geologic history. It is impossible, therefore, for historical geologists to be indifferent to the results of any investigation that promises to throw light upon the thermal endurance of the sun.

The central subject of interest in the recent observations, the constitution of the corona, may seem quite remote from any geologic relationship, but, as in so many other cases in the history of science, light upon dark problems may come from an unexpected source. It is not beyond the limits of speculation to conceive that the corona may prove to be the very phenomenon that will point the way to a revised estimate of the thermal possibilities of the sun and thus to a revised measure of its past duration and of the age of the earth as one of its dependencies. Some hint of the possibilities may be found in the logical sequences of one of the alternative working hypotheses relative to the coronal nature. If the conception that it is formed of extremely attenuated matter driven away at great velocities, after the analogy of the tails of comets, should be substantiated, it will necessarily be followed by the problem of the origin of such attenuated matter. In the case of comets such supposed matter may be assumed to be simply an accessory constituent brought in from distant space and developed by approach to the sun — and soon exhausted in the case of captured comets — but such a

hypothesis does not seem well fitted to the sun itself in this late stage of its history. The alternative conjecture that the attenuated form of matter is developed in the sun by the extraordinary agencies operative there must obviously be entertained until disproved, and the recent investigations of J. J. Thompson and others with reference to the extremely attenuated ionization of terrestrial gases under certain conditions render such a hypothesis less highly improbable than it would have seemed under the dominance of the inherited doctrine of the indivisibility of the atom.

A speculation which involves the notion of the divisibility of the atom involves also that of the divisibility of the internal energies of the atom and their possible transformation into radiant energy, and hence a possible source of heat of unknown and, at present, quite incalculable amount.

So too, a speculation which assumes that the corona is radiated matter involves also the conception of loss of sun's substance if the velocity of radiation be as high as that attributed to the conjectural matter of comets' tails; and if this loss of matter in the course of great secular periods becomes appreciable, it may require a reconsideration of the data upon which estimates of the sun's heat are based and also of a revised consideration of the former distances of the planets.

Now such an attenuated chain of hypotheses, each dependent on an antecedent hypothesis of uncertain verity, may be altogether too unsubstantial to have any appreciable value of the positive sort, other than as the antecedent of investigation, but it may have the negative virtue of helping to keep open the question of the sum total of the sources of the sun's heat and its possible duration in the past and the future. And so possibly may also the logical sequences of the alternative coronal hypotheses. The Helmholtzian theory assigns a source of heat of such competency that it cannot be proved not to be the sole essential cause by any measurements of the sun that can be made now, or probably in the near future, and hence it satisfies the immediate demands of astronomical science, however inadequate it may be to meet the natural interpretations of geological and biological data;

but it may be conjectured that when the history of the stellar system shall become as serious and substantial a subject of study as the history of the earth now is, astronomers will find at least as great need for long lapses of time and for the secular endurance of thermal states as do the geologists and biologists.

Meanwhile all solar inquiries are subjects of acute interest in common and the achievements of May 28 are matters of heartiest congratulation. T. C. C.

THE George Huntington Williams Memorial Lectures, inaugurated in 1897 by Sir Archibald Geike, have been continued this year by Professor W. C. Brögger, of the University of Christiania, who delivered at the Johns Hopkins University two lectures on The Principles of a Genetic Classification of the Igneous Rocks, and five lectures on The Late Geological History of Scandinavia, as shown by changes of level and climate in southern Norway since the close of the glacial epoch. His long and thorough investigation of the igneous rocks of the Christiania region, so varied in character, well preserved and finely exposed, has qualified him to speak with authority upon the subject of their genetic relations, and renders his judgment upon the general problem of the classification of igneous rocks of the first importance. Until the text of these lectures has been published, it will not be in place to discuss the conclusions enunciated by Professor Brögger. The lectures on The Late Geological History of Scandinavia were based upon recent field studies of the glacial phenomena of that region. In addition to their special scientific value, they illustrate the remarkable versatility and energy of Professor Brögger, whose substantial contributions to the paleontology and stratigraphy, the mineralogy and petrology of the Christiania region have already awakened the admiration of his fellow workers.

Professor Brögger also delivered his lectures on the Genetic Classification of Igneous Rocks at the University of Chicago to an appreciative audience of students and geologists, who assembled from various parts of Illinois and from Michigan, Wisconsin, and Minnesota. J. P. I.

REVIEWS

A Preliminary Report on the Geology of Louisiana. By GILBERT D. HARRIS, geologist in charge, and A. C. VEATCH, assistant geologist. Made under direction of State Experiment Station, Baton Rouge, La. Wm. C. Stubbs, Ph.D., director. [No place or date.]

This report is divided into three sections: I, Historical Review; II, General Geology, and III, Special papers.

In view of the important disagreements between the earlier writers upon Louisiana geology and the authors of this volume the historical review with which it opens is especially important and interesting. The full meaning of this review is only clear after one reads the second part and some of the third part of the volume. The lowest horizons represented are Cretaceous, and the earlier determination of these beds seems to have been based upon the occurrence of a single species, *Exogyra costata*. The present survey has been able to get together a a fairly good representation of the Cretaceous fauna of the state (p. 292–297).

The Mansfield of Hilgard, which was referred by Hopkins to the Jackson (p. 29–35) at the top of the Eocene, turns out to be Lower Lignitic Eocene (pp. 64–73), a horizon not hitherto known to exist in Louisiana. The conclusions reached in regard to the Cretaceous give us a new view of the general geology of the state. The dips and many other facts cited "indicate northeast-southwest local folds parallel to the old shore lines," rather than a northwest-southeast mountain chain (p. 62.) Of the Vicksburgh beds which some of the earlier writers thought they had found between Red River and the Sabine, Professor Harris says "we have found no trace of Vicksburg deposits west of Red River" (p. 90).

A part of the second section of the report is devoted to Economic Geology, and under this head are given valuable data regarding the salt, sulphur, and clay deposits of the state. Among the special reports are several of more than unusual interest. One of these is Mr. Veatch's paper upon "The Shreveport Area." Under this head he

treats at length "the great raft"—a subject of deep interest to geologists (pp. 160–173). He explains its origin, method and rates of growth and decay, and describes the effects of such accumulations and of their removal. He makes some interesting observations upon the lakes of the area, which he classes as: (1) cut-off or horseshoe lakes; (2) lakes of enclosure; and (3) raft lakes. The "raft lakes," it seems, have been attributed to a sinking of the land, but Mr. Veatch thinks they have been formed by the choking up of the former drainage by the accumulation of drift timber in old stream channels (p. 188). The activity of geologic agents in regions of such sluggish drainage has evidently not been realized hitherto, for here in a region at or close to its base level "Lakes have been formed and destroyed; streams have been formed and abandoned; waterfalls produced to destroy themselves; new streams formed out of parts of the beds of old ones and temporary reversals of the drainage systems have been affected" (p. 154). The articles on the Five Islands (pp. 213–262) is by far the most thorough and satisfactory that has yet appeared upon the remarkable salt deposits of Louisiana. The investigation of the clays by Dr. H. Ries is a valuable piece of work done by one of our best authorities on the subject.

Papers of paleontologic interest are given in the third section by Professor Harris upon the Natchitoches area, and upon the Cretaceous and Lower Eocene faunas of Louisiana. These papers are illustrated by seven beautifully prepared plates. Professor Harris also contributes a paper upon meridian lines, and another upon road making. This last subject is entitled to the serious attention of the people of Louisiana. That the geologists are unable to make the most of their time because of the bad roads of the state is to be regretted, and the geologists have our sympathy, but when many of these roads become such quagmires for several months of the year that traffic over them comes to a dead standstill, it is a matter that more or less seriously affects the prosperity and happiness of the entire population.

Arthur Hollick contributes a well illustrated and valuable article upon the Lower Tertiary plants from the northwestern part of the state (pp. 276–288, and 16 plates).

It is pleasant to see that Dr. Stubbs, the director of the State Experiment Stations, under whom the geological survey is being made, appreciates the fitness, ability, and enthusiasm of the men who are doing the work. Indeed it would have been difficult if not impossible to have

found a man better fitted than Professor Harris to take charge of the study of Louisiana geology. The problems of the stratigraphy of the state can be attacked successfully only by a careful study of the fossils. The promptness with which the report has been published is one of its many virtues. The work was begun in November 1898, and Professor Harris' letter of transmission is dated November 1899. Such promptness, however, sometimes has its disadvantages. It is doubtless responsible for several important typographical errors, for the awkward title-page that gives neither date nor place of publication, and for the unfinished condition in which the maps appear. Perhaps it is just as well that the geological map accompanying the report is credited to no one, for to no one is it a credit. With the exception of the maps the volume is well printed and tastefully bound; and the defects we may find in the mechanical part of the work are very small matters compared with the valuable contributions to science contained in the report.

JOHN C. BRANNER.

On the Lower Silurian (Trenton) Fauna of Baffin Land. By CHARLES SCHUCHERT, Proc. U. S. Nat. Mus., Vol. XXII, pp. 143–177, plates XII–XIV.

Any addition to our knowledge of the fossil faunas of the arctic regions is received with special satisfaction by those who are interested in the broader problems of palæontology, in which the facts of geographic distribution are of special moment. The present paper by Mr. Schuchert is one of the most important of such contributions to be found in our literature. It is devoted to the description and discussion of more complete collections of fossils from Sillman's Fossil Mount at the head of Frobisher Bay, than have previously been secured from that locality. Seventy species of fossils are recorded, eighteen being described as new. The fauna shows strong affinities with the Trenton fauna of the United States, especially with the fauna of that age as it is known in Minnesota, a large proportion of the species being common to the two regions.

The Trenton fauna has been recognized at various localities in the arctic regions, the strata containing it always resting unconformably upon the old crystalline rocks. No other Ordovician fauna has been recognized in the whole region save at one locality, on Frobisher Bay,

where a few species indicating a fauna of Utica age have been collected. In general the Trenton beds are followed immediately by strata containing a Silurian (Upper Silurian) fauna of Niagara or Wenlock age.

STUART WELLER.

The Glacial Palagonite-Formation of Iceland. By HELGI PJETURSSON, Cand. Mag. Copenhagen. The Scottish Geographical Magazine, May 1900, Vol. XVI, No. 5.

This appears to be a very important contribution to the history of Pleistocene glaciation. It opens up a new and very promising field, whose data are peculiar because of their association with volcanic phenomena. The author presents in much detail, and with apparent care and discrimination, evidence of glacial formations antedating the so-called "preglacial" lava flows, as well as others interstratified with the lava flows. After twenty-two pages devoted to description of details, illustrated by figures, the author draws the following important conclusions:

I shall not be surprised if this account of the occurrence of glacial deposits and striated rock surfaces in connection with the "palagonite-formation" of Iceland is received with incredulity. For myself, I could hardly believe the evidence when I first encountered it, and tried to explain it in every possible way other than by glacial action. But the glacial origin of the "breccias" could not be gainsaid. Not only did they present a characteristically morainic aspect, but they yielded numerous well striated stones, and in places were found to be resting upon grooved and striated rock surfaces. If the observations I have here recorded be accepted as fairly trustworthy, we cannot avoid the conclusion that glacial deposits, hitherto unrecognized as such, are largely developed in Iceland, or at all events in that part of the island which I have critically examined and referred to in these pages.

As I have had only a glimpse, as it were, into this very promising field of glacial research, I shall not attempt to deal with the glacial succession in Iceland. That must be left for future investigations to determine. Nevertheless there are several conclusions which seem to me obvious enough. Of these the most important, in my opinion, is that which has reference to successive glaciations. The facts advanced show that Iceland has experienced more than one glaciation before the ejection of the doleritic lavas and their subsequent smoothing and grooving by ice. How many separate glaciations the morainic breccias bear witness to is uncertain. But the repeated occurrence of four separate sheets or beds of morainic breccia seems to render it not improbable that there have been just as many separate glaciations during the

accumulation of the so-called palagonite formation. Even if we discard the evidence furnished by the lowest breccias (in which, it will be remembered, that notwithstanding their morainic aspect, no striated stones occurred), we have still the overwhelming evidence of glaciation supplied by the higher morainic breccias. But whether these indurated ground moraines represent three, four, or more glaciations, one or other of them must represent the epoch of maximum glaciation in Europe. The glaciation which left the older system of markings on the dolerite of Stangasfjall is, of course, of later date and may possibly represent the Mecklenburgian stage (Geikie) of northern Europe, and the first postglacial stage of glaciation of the Alps (Penck). It seems more than probable that a change of climate, corresponding to that which in the Alps depressed the snow line about 3000 feet, would bring about the total glaciation of Iceland. Indeed, a much less important change in the climatic conditions would suffice to do this. It is therefore quite possible that the younger system of striae marking the surfaces of the dolerites may be contemporaneous with that readvance of cold conditions which produced the local glaciers of the "Lower Turbarian stage" of Scotland, and those of the "Second postglacial stage" in the Alps.

[The second striated horizon in the moraine of Sudurnes (if it be not a striated pavement) may possibly indicate a third "post-doleritic" glaciation, but until additional evidence be forthcoming, this isolated observation must be left out of consideration.]

So far as I know, all that has been written on the glacial period in Iceland refers to the minor glaciations which supervened after the ejection of the doleritic streams of lava. I say minor glaciations, even although the country appears during those stages to have been totally ice-covered. But the mass of the "palagonite-moraines" is so very much greater than that of the loose accumulations of the later glaciations, that we may reasonably infer that the former are products of much greater ice-sheets. Moreover, the conditions of erosion and accumulation during successive glaciations seem to have differed at the same localities. Further, when we remember that the whole region throughout which the palagonite-formation occurs, has been extensively fractured and consequently has experienced many subsidences—and when we reflect that all these important deformations of the land surface took place subsequent to the accumulation of the uppermost morainic breccias, we are led to suspect that the area over which the older glaciations prevailed may have considerably exceeded that which now exists. Probably conclusive evidence on this point may be obtained by studying the directions of the oldest glacial striae all over the country, and more especially in the north.

It would probably also be of great interest to determine the relations of the Pliocene shell-beds near Húsavík, North Iceland, to the "tuff- and breccia-formation." As I have obtained a grant from the Carlsberg Fund,

Copenhagen, to enable me to continue these investigations, I hope to do so on the lines here indicated.

About 5500 square miles of the total area of Iceland are at present covered with glaciers. The country, therefore, would seem to be in a state of glaciation comparable to that obtaining in Scotland during the fourth glacial epoch as defined by Professor Geikie. Now, if Iceland were to be once more totally glaciated, should we term that final ice-invasion a separate stage of glaciation; or merely an oscillation of the existing glaciers? Would the present inhabited condition of Iceland be considered an interglacial epoch, or merely a stage of temporary glacial retreat?

Such considerations must be kept in view when we are discussing whether the old ground moraines described in this paper have been laid down by an oscillating ice-sheet or during separate glacial epochs.

In Búrfell two bottom-moraines are separated by 150 to 200 feet of basalt, on the striated surface of which the upper moraine reposes. Possibly, however, that basalt does not mark the lowest interglacial horizon.

To the next succeeding interglacial horizon probably belong the conglomerates of Stangarfjall, Bringa, and Hagafjall, which are supposed to be of fluviatile origin. Perhaps also the columnar dolerite of Stangarfjall should be included here. The existence of those conglomerates at such heights and so far inland suggests at least a very considerable oscillation of the ice-sheet. Moreover, we must not forget that the conglomerates in question are buried underneath masses of various volcanic products. [While some of the old gravel beds may well represent old river channels, in other places, as in Hagafjall and Bringa, they had more the character of lacustrine deltas or *cônes de déjection*.]

The next interval between two glaciations is that marked by the so-called "preglacial dolerites" which henceforward cannot claim to be more than interglacial. "At the time these preglacial lava beds were laid down, the country had pretty much the same essential contours that it has at present."[1] But when the uppermost of the "palagonite-moraines" (as in Berghylsfjall and Hagafjall) were laid down, the relief of the country, as we have seen, differed greatly from that which now obtains. In the interval of time that separates these morainic breccias from the eruption of the later lavas, the most radical changes in the contours of the country had been effected, chiefly perhaps by subsidence. The southern lowland of Iceland cannot date farther back than this interglacial epoch.

It is not improbable, indeed, that the essential contour lines or surface features of the whole island, so far as these are older than the later outflows of dolerite, came into existence during this interglacial epoch. We cannot tell at what particular stage the later dolerites were erupted, but we know

[1] Thoroddsen, Explorations etc., p. 35.

that the changes of relief which were effected during the interglacial stage in question were very much greater than those which have taken place since the outflow of the doleritic lavas. And yet these lavas have been glaciated more than once, and we do not know how long they had to wait for their first glaciation.

We seem therefore justified in coming to the conclusion that the two glaciations in question have not been the result of comparatively insignificant oscillations of an ice-sheet, but were really separated by a protracted period. The very occurrence indeed of the interglacial streams of lava over such great areas suffices to show how extensively the ice-sheet melted away. It seems to me highly probable that *all* the so-called "preglacial" lavas are in reality interglacial.

Furthermore, the evidence leads to the inference that the time which has elapsed since the last ice-sheet disappeared from the southern lowland of Iceland is very short as compared to the interglacial epoch that intervened between the first of the glaciations experienced by the dolerites and that next preceding it.

Whether the supposed marine deposit which underlies the glaciated lava on Tungufljót dates back to the closing stages of the interglacial epoch just mentioned, or whether it ought rather to be ascribed to an interval separating the two glaciations which are represented by the two systems of striae upon the surfaces of the later dolerites, future investigations must be left to determine.

No doubt many additional conclusions are suggested by the observations recorded in this paper, but I do not care to consider these at present. As already stated, the chief object of this paper is to point out that there exists in Iceland much hitherto unsuspected evidence of former glacial action. I am indeed sanguine enough to think it not improbable that the records of the glacial period have been more fully preserved here than elsewhere. For it is obvious that the conditions for the protection and preservation of glacial deposits have been with us somewhat exceptional. While in other lands, free from volcanic activity, each succeeding ice-sheet has partly destroyed and partly covered up the deposits of its predecessor, in Iceland the moraines have been greatly sheltered by the products of volcanic eruptions which overlie them. Moreover, crustal movements have contributed directly toward the same end by placing the old moraines beyond the reach, as it were, of succeeding glacial invasions. Not improbably, too, some rocks of the "tuff- and breccia-formation" may be due to the direct interaction of volcanic and glacial forces.

To this is added the discussion of some points of a more special and local nature. It is gratifying to learn that the investigation is likely to be continued. T. C. C.

Fossil Flora of the Lower Coal Measures of Missouri. By DAVID WHITE. U. S. Geological Survey, Monograph XXXVII, 468 pp., 1900.

The coal floras are always of great interest. The present contribution is the most important that the central-West has seen since the appearance of Lesquereux's classic work of a quarter of a century ago. The title of the volume does not, however, express the real scope of the work. Most of the forms come from a single locality, near Clinton, in Henry county, Missouri, and from a single horizon — the Jordan coal. The latter is the lowest workable coal seam in the district and is only about 100 feet from the base of the Coal Measures.

While the greater part of the monograph is taken up with the minute descriptions of species, and discussions of the biological relationships of these, the chief interest to the stratigraphical geologist is centered in the data furnished for broad correlations.

Regarding the probable stage of the lower coals of Clinton in eastern sections, Mr. White says: "If we take Henry county, from which most of our evidence, both stratigraphic and paleontologic is drawn, as the stratigraphic type of the base of the Coal Measures of the state, and assume that the conditions are constant along the margin of the coal field in other counties, the evidence of the fossil plants, so far as they are now obtainable, appears to indicate the deposition of the lowest coals in the state at a time subsequent to the formation of the lower coals of the Lower Coal Measures of the eastern regions, including the Morris coal of Illinois, the Brookville and probably the Clarion coal of Ohio and Pennsylvania, yet perhaps earlier than the formation of the Darlington or upper Kittanning coals of the two states last named.

"The study of the distribution of the Henry county flora in this field shows its closest relations in coals D and E, locally known as the 'Marcy' and the 'Big' or Pittston coals. But in view of the fact that the E coal of the Pittston and Wilkesbarre regions seems to carry many types of a more modern cast, it is not likely that the Missouri stage is so high in the series as that coal. In the plants of the D coal, not only are a large part of the species identical with those from Missouri, but the flora as a whole is of a similar type. Compared, however, with the somewhat equivocal combined flora reported from the C coal, the material from the Mississippi valley appears on the whole fully as recent, while lacking many of the older types found at several

of the mines correlated by stratigraphy with that coal. Hence I am inclined to regard the plants from Henry county, Missouri, as more clearly contemporaneous with those in the roof of the D or 'Marcy' coal in the northern anthracite field, though they are possibly as old as the C coal."

The reference to the unconformity at the base of the Missouri Coal Measures is full of significance. "The transgression of the water level during the early Mesocarboniferous time has already been discussed by Broadhead, Winslow, and Keyes, the state geologists. The evidence of the fossil plants not only corroborates their views in general, but it also fixes the time of the encroachment of the sea on the old coast in the region of Clinton. The paleobotanic criteria indicates that the minimum time represented by the unconformity between Jordan or Owen coal and the subjacent Eocarboniferous terrane is measured by the period required for the deposition of the Pottsville and the Clarion group of the Lower Productive Coal Measures, a series of rocks reaching a thickness of over 1200 feet in portions of the anthracite regions, and exceeding 2400 feet in southern West Virginia."

The depositional equivalent of the unconformity at the base of the Missouri Coal Measures is even more important than Mr. White has indicated. As quite recently stated there is farther south in Arkansas, a sequence of Coal Measures beneath the basal horizon of the Des Moines and Missourian series combined. In reality the geological position of the Lower Coal Measures (Des Moines series) of Missouri appears to be well up in the median part of the Middle Carboniferous instead of at the base, as generally considered. Only in Missouri, about one half of the Middle Carboniferous is unrepresented by strata. This lacking series may be represented in Arkansas by upwards of 12,000 feet of sediments!

Attention is called in the monograph to some of the obstacles to accuracy in correlation and especially to the lack of standard paleobotanic sections. If ever there were opportunity of establishing a standard section of this kind it is in the Trans-Mississippian coal field. Plant remains occurs abundantly in many localities and at many horizons extending from the very base of Des Moines, up through the Missourian, into the so-called Permian. The monograph on the Missouri fossil floras considers chiefly one locality and one horizon. In Missouri alone there are no less than 150 known localities and 30 horizons for coal plants. In Iowa there are nearly as many more.

Kansas likewise offers an equally inviting field. If a single location yields up such prodigious possibilities as Mr. White has demonstrated what may we not expect from the rest of the vast field!

C. R. KEYES.

The Devonian "Lamprey," Palaeospondylus Gunni, Traquair. By BASHFORD DEAN (Mem. N. Y. Acad. Sci., Vol. II, Part I), 1899.

This elaborate memoir of thirty quarto pages and a plate drawn and lithographed by the author himself represent a vast amount of labor expended on minute, poorly preserved, and what would seem at first sight insignificant objects, found in the Caithness flags of Scotland. The fossil remains of *Palaeospondylus* are very unsatisfactory for study, and but for the peculiar interest attaching to them as supposed representatives of Palaeozoic Lampreys, they would hardly command attention. But zoölogists have been eagerly awaiting whatever enlightenment palaeontology might offer on the relations and descent of the Cyclostomes, and when Dr. R. H. Traquair announced his discovery of *Palaeospondylus* in 1890, it was hailed with delight as a definite clew to Cyclostome genealogy.

Dr. Dean observes: "Zoölogists were by no means unwilling to accept *Palaeospondylus* as a fossil lamprey; and they even found it a difficult matter to avoid going out in the road to give it a charitable reception. The fossil came, was seen, and was currently accepted. But time has gone by and suspicion come, and the thought is by no means comforting that the wrong prodigal may have been welcomed. Is *Palaeospondylus*, then, a veritable Cyclostome, or is it at least a provisional one?" Dr. Dean's purpose in investigating this question is a critical one, and he states that he has "attempted to analyze the results of preceding writers, to contribute some further data to our knowledge of the structure of this form, and to endeavor finally to determine what conclusions are justified in assigning a place to this fossil. After accomplishing all this in very satisfactory fashion, the author takes up the classification of fishlike vertebrates in general and introduces some novel changes, which will be referred to presently.

Dr. Dean's conclusion as to the Marsipobranch nature of *Palaeospondylus* takes the form of a more emphatic denial than ever (see his previous paper in *Proc. Zoöl. Soc.*, April 1898) that it can be regarded

even provisionally as a fossil lamprey. Dr. Traquair's objection that if *Palaeospondylus* be not a Marsipobranch it is impossible to refer it to any other existing group of vertebrates, Dr. Dean disposes of by boldly placing it in a new class by itself, elevating the order Cycliae, which Gill created for it, to that rank. Such a course may strike one as rather startling, perhaps, but it is certainly effective. An alternative proposition which Dr. Dean suggests may be more acceptable to some ichthyologists "is to place it with *Coccosteus* as doubtfully its larval form." Although there is considerable reason for regarding the variations in this small form as the early stages of some larger chordate, yet there is no direct proof that the adult form was an Arthrodire; hence this association would have to be at best only provisional, and, in the author's opinion, is inexpedient. As to the relations of newly exalted Cycliae to other classes, we are left as much in the dark as ever. Some very excellent figures of the fossil forms are given, together with a diagrammatic restoration.

Very interesting, indeed, are the author's views on the systematic arrangement of the early forms of fishlike vertebrates and fishes proper, with which the paper concludes. Amongst the latter the Chimaeroids are reduced again to the rank of an order instead of a subclass, principally as the result of Dr. Dean's recent embryological investigations, and the Dipnoi are reduced from class rank (Parker) to that of a subclass. *Acanthodes* and *Cladoselache* are grouped together under the primitive Elasmobranch order Pleuropterygii.

Turning now to the most primitive of all chordates, Dr. Dean elevates the Ostracoderms and Arthrodires each to the rank of an independent class, the former with its customary triple subdivision, but the latter separated into two new divisions, Arthrodira proper and Anarthrodira, which rank as subclasses. On the ground of their lacking a mandibular arch and paired limbs, the Ostracoderms were denied by Cope, and following him by Smith Woodward, and others, to be fishes at all, but organisms far removed from the latter, called "Agnatha." The origin and relations of the Ostracoderms are at present among the most important and fascinating questions of palaeichthyology. Dr. Traquair, in an extremely valuable memoir of last December[1] refuses to believe that these forms are Agnatha, declaring Cope's view to rest entirely on negative evidence, and preferring to look upon the lowest

[1] Report on Silurian Fishes (Trans. Roy. Soc., Edinburgh, Vol. XXXIX, Pt. III), 1899.

Ostracoderms "as having definitely split off from the Elasmobranchs, from which they doubtless originally came." Dean believes in a wider separation, however, from the groups represented by recent forms; but regarding the differences between Ostracoderms and Arthrodires, he makes the following significant remark: "A renewed examination of the subject has caused me to incline strongly to the belief that Pterichthys and Coccosteans are not as widely separated in phylogeny as Smith Woodward, for example, has maintained. But as far as present evidence goes, they appear to me certainly as distinct as fishes are from amphibia, or as reptiles are from birds or from mammals" (p. 24). The reference to Smith Woodward bears, of course, on the recognition of Arthrodires by that author as an order of Dipnoi.

Whatever may be thought of the class Cycliae, there is no question but that Dr. Dean has scored an advance by elevating the Ostracoderms and Arthrodires to a higher rank and placing them in close proximity to one another. A separation of the two classes is rendered necessary of course, thus prohibiting the revival of McCoy's "Placodermata," by the absence of "jaws," endoskeletal structures, and paired limbs in the first-named group. Nevertheless the two classes have a number of points in common, and should we be led to infer with Traquair an Elasmobranch derivation of the Ostracoderms, it would be natural to trace Arthrodires to the same source. Whether there were really "Agnatha," and how far the archaic fishlike vertebrates were removed from the groups represented by living forms, must be left for future study to decide. Or possibly we may never have the solution of these perplexing problems.

In one minor point only the reviewer finds himself in disagreement with Dr. Dean, and this relates to the subdivision of Arthrodires (or "Arthrognaths," to use his new term) into Arthrodira proper and Anarthrodira. The latter includes *Macropetalichthys*, *Trachosteus*, *Mylostoma*, and certain transitional forms which the author promises shortly to describe. When the cranial and body armoring of *Trachosteus* and *Mylostoma* are made known, their position may become evident. At present we are acquainted only with the cranial osteology of *Macropetalichthys*, and this is so far different from that of typical Arthrodires that in the reviewer's opinion it cannot be retained in the same class. As typical of an independent family, it had best be removed with the Asterosteidae to a position amongst the Ostracoderms, as we certainly do not wish to make of it an independent class. The comparisons between

this form and the cranial and dorsal shields of Arthrodires indicated by Cope and the reviewer a few years ago were based upon a misconception of the septum dividing off the so-called "nuchal plate;" but in reality no homology exists between arrangement of cranial plates or the sensory canal system of this form and those of Arthrodires. No plates corresponding to the dorsal or ventral armoring of *Coccosteus*, etc., are known, nor is there any evidence of a lower jaw, of paired fins, neural or haemal arches, nor any form of dental plates attached to the roof of the mouth. Finally, the bone-structure is perceptibly different from that of typical Arthrodires, and the under side of the head is unparalleled in the latter group. This form is certainly worthy of careful reinvestigation.

The whole matter of Dr. Dean's Anarthrodira, is, however, of subordinate importance as compared with his main theme, which is admirably treated; and palaeontologists will be sure to appreciate his clear exposition of the same, supplemented as it is by a complete bibliography and expertly drawn figures.

C. R. EASTMAN.

Some High Levels in the Postglacial Development of the Finger Lakes of New York. By THOMAS L. WATSON. With 30 figures and 3 maps. The figures being mostly full page half-tones, maps, and diagrams. Appendix B. Report of the Director of the New York State Museum, 1899.

Dr. Watson presents in a very clear and interesting manner the results of the earlier works of other investigators and of his own extended observations on the high level terraces and water marks in the Finger Lakes region. He finds that at the time of maximum advance of the "ice of the second glacial period" (by which he probably means the early or late Wisconsin of some writers) the ice front extended to and beyond the present divide which separates the waters draining northward into the St. Lawrence and those of the Chemung-Susquehanna draining to the southward. The preglacial valleys now occupied by the Finger Lakes were entirely overridden by the ice but were not completely filled with the glacial débris, so that as the ice front began to retreat and had drawn back to a position north of the divide there was formed, in the valleys, numerous local glacial lakes which drained southward through several channel ways. These channel

ways were at different levels for the different lakes and as the ice front drew back to the northeast, the several local lakes coalesced into fewer larger bodies of water and the higher outlets were abandoned in succession until finally there was but one body of water, Lake Newberry, with a single outlet to the southward. This outlet was finally abandoned when the waters of Lake Newberry fell to the level of and coalesced with those of Lake Warren. At last the opening of the St. Lawrence and the lowering of the Lake Iroquois left the waters of the present Finger Lakes in the old valleys, held back by drift barriers. The evidence for this sequence of events, which the author traces with much detail, is found largely in the high level delta deposits made by the tributary streams in the temporary glacial lakes at the levels of the southern outlets which mark the successive stages of water levels. Dr. Watson's map of the temporary, local, glacial lakes of the Finger Lakes region suggests that under similar relations of ice front to topographic form, such as undoubtedly prevailed farther westward in New York and through northern Ohio, the results of glacial action would be much the same and that if we are to arrive at a correct interpretation of the sequence of events during the Pleistocene it will be through the detailed study of many limited areas in the careful painstaking manner shown by the work of Dr. Watson. Such work cannot be too highly commended. W. G. T.

Twentieth Annual Report of the U. S. Geological Survey, Mineral Resources of the United States, 1898. Washington, D. C. 616 and 804 pages.

The annual report on the mineral resources for 1898 like its predecessors contains much valuable statistical and descriptive matter on the different mineral products of the United States. The data in the present report have been brought up to the close of 1898 and, as has been customary since 1894, when this publication was first made a part of the annual report, along with the statistical matter there is included valuable information on the industrial uses, improvements on ore reduction, new developments, distribution of ores, chemical analyses, and other data concerning the different products. The statistics on some of the products are given in great detail, thus nearly one hundred pages are devoted to a discussion of the iron ores and the American and foreign iron trade, which is not an undue proportion of space

when we consider that the value of iron for 1898 was 116.5 millions of dollars against 227 millions for all the other metallic products. Likewise 314 pages are given to the coal and coke industries but the value of the coal alone is 208 million dollars against 145 millions for all other non-metallic products. The total value of all the mineral products for 1898 is $697,820,720 which is an increase over the preceding year of $66,966,791 or 10.62 per cent.

Some of the more important special topics discussed are (1) the history of gold mining and metallurgy in the southern states by H. B. C. Nitze; (2) the characteristics, uses and domestic and foreign production of manganese ores by John Birkinbine; (3) the slate belt of Eastern New York and Western Vermont by T. Nelson Dale; (4) more than 100 pages of analyses and tests of building stones collected from various sources by Wm. C. Day and classified and arranged by states; (5) a brief reconnaissance of the Tennesse phosphate fields by C. Willard Hayes; (6) the mica deposits in the United States by J. A. Holmes; and (7) the mineral resources of Porto Rico by Robert T. Hill, and H. B. C. Nitze.

T. C. H.

Les Charbons Britanniques et Leur Épuisement. By ED. LOZÉ. Two volumes. Paris, 1900.

This work is an exhaustive treatise on British coals, comprising a discussion of their history, exploitation, production, consumption, geological occurrence, value, qualities, classification, utilities, and exportation. The work as whole is divided into four parts. Part one presents a general discussion of the geography and inhabitants of Great Britain and Ireland; their social, political, and economic conditions; the influence of the coal industry on economics, navigation, naval power, and the national debt; the geology of the British Isles; the history of coal production and the statistics bearing on its production and consumption.

Part two furnishes a description of the coal beds of the United Kingdom and discusses their importance and productiveness. This is followed by a series of chapters on the industrial and commercial geography of the Islands, constituting the third part of the work. The fourth part treats of the productiveness of the coal mines, and the probable time of depletion.

It is thought probable that coal was first used in Britain by the early Bretons, but direct evidence of it is wanting. However, it is known to have been used by the Roman invaders, as cinders and coal ashes have been found in the ruins of the Roman houses. Not much is known of the coal industry from the time of the Roman invasion until the beginning of the thirteenth century when it is referred to in certain land grants. The first mines were located in the vicinity of Newcastle. By the year 1379 coal had become of sufficient importance to make it an object of impost. By the beginning of the sixteenth century the production had reached an average of a million tons per year, and the total production from that date to 1866 is estimated to be 850 million tons.

The principal coal beds of the United Kingdom occur in the Coal Measures or upper part of the Carboniferous series. According to Hull the Lower Carboniferous has a threefold division: (1) the lower schist group, (2) the Mountain limestone, and (3) the Yoredale group. The Upper Carboniferous is divided into (1) the Millstone grit, (2) the lower Coal Measures, (3) the middle Coal Measures, and (4) the upper Coal Measures. The last three divisions contain the productive coal beds. The work is accompanied by maps locating accurately the known coal areas and giving the probable extent of the undetermined ones.

The coals of Britain are classed under the heads of:

1. Lignites, containing 67 per cent. of carbon and 26 per cent. of oxygen.
2. Bituminous coal, containing 75 to 90 per cent. of carbon and 6 to 19 per cent. of oxygen.
3. Steam coal, a sort of semi-anthracite.
4. Cannel coal, containing 40 per cent. of volatile matter and being rich in hydrogen.
5. Anthracite coal, containing 93 to 95 per cent. of carbon and 3 per cent. of oxygen with 2 to 4 per cent. of hydrogen.

The total exportation of coal from the British Isles in 1898 was 35 million tons, which was a decrease over the preceding year of about 300,000 tons. The importation of coal for 1897 was only 9454 tons. The amount of coal consumed per capita in 1898 was 3.867 tons.

The author discusses the estimate made by the Commission of 1870, that the coal resources of the United Kingdom are 80 billion tons, and that at the present rate of depletion (2 million tons per year)

the total exhaustion will take place in four hundred years; and arrives at the conclusion that the time may be even less than that given by the Commission. That the day of complete depletion will come, the author is assured, and when it does come "the historian of a powerful empire will terminate, very probably, the narrative of a remarkable epoch with these words, *finis Britannae.*" W. N. LOGAN.

Cape Nome Gold Region. By FRANK C. SCHRADER and ALFRED H. BROOKS. United States Geological Survey, Special Report, 56 pp. Washington, 1900.

The Cape Nome gold field which has recently occasioned so much excitement is of special interest geologically on account of being the most noteworthy modern beach placers known. The type of ore deposits to which these Alaskan beds belong has long been recognized, but no bodies of this kind have ever proved so rich. Ancient deposits of the same origin are not unknown. Such are the Witwatersrand blanket of the Transvaal and the Napoleon Creek conglomerate in Alaska.

The Ncme district is on the southern shore of the Seward peninsula in a little known part of northwestern Alaska. "The beach rises gradually to a sharply cut bench, a hundred to two hundred yards from the surf. From the edge of this terrace, which is about twenty feet high, the moss-covered tundra extends inland, rising uniformly about two hundred feet in four or five miles, when it merges into the highland belt."

The bed-rock of the region is composed of limestones and phyllites or mica schists interbedded, with some gneiss. Igneous rock is of rare occurrence. Over this foundation lie the unconsolidated gravels with gold-bearing zones. The authors emphasize the fact that during the deposition of the gravels and sands the conditions were not materially different from those of today, except that the land stood at a lower elevation relatively to the sea. "There is no evidence whatever of glacial action in the region, and the popular idea that the gravels were brought to their present position by ice action is entirely erroneous."

The gold-bearing deposits are grouped into gulch-placers, bar-placers, beach-placers, tundra-placers, and bench-placers. The gulch and beach placers are the most productive. During the past year (1899) the production was three million dollars.

The gold is usually rounded and often smoothly polished. It is not evenly distributed through the gravels but gathered in zones. In

washing the pay-streaks the heavy minerals garnet and magnetite are concentrated along with the gold. The first forms "ruby sand" and the latter "black sand."

Good prospects for gold occur in many other places in the Seaward peninsula. "The geographic portions of some of the different localities suggest that they may belong to the same gold belt. The facts known to us, however, are not sufficient to prove this; and it must simply be regarded as a working hypothesis. Should subsequent development and investigation show that the gold of all of these districts of Seward peninsula is derived from the same series of rocks, this gold-mining region will embrace an area of at least 5000 to 6000 square miles. If this proves to be the case, it does not by any means follow that the entire belt will contain workable gold deposits. We should rather expect to find the gold confined to certain zones within the belt."

The report is accompanied by a number of excellent views of the region. This preliminary report gives us a good idea of just what the visitors and prospectors may expect when they reach the Cape Nome region. Scientists will await the appearance of the final report with interest.

C. R. KEYES.

Syllabus of Economic Geology. By JOHN C. BRANNER, Ph.D., and JOHN F. NEWSOM, A.M., Second Edition, 1900, pp. 368. Plates and Diagrams.

This volume is a syllabus of a course of lectures on economic geology given by the authors at Leland Stanford Junior University. It is intended primarily for the student, but will also be found a most valuable guide to anyone interested in the various branches of economic geology. It begins with a general list of the more important works on economic geology, and of the periodicals relating to this subject. After this are a few introductory remarks on geology in its relation to various economic subjects, including mining, agriculture, forestry, manufacturing, industries, art, roads, railways, migration, etc., followed by a brief synopsis of geological sections, maps, surveys, etc., from an economic standpoint; a summary of economic geological products and their various classifications as proposed by different authors; rock-cavities; the formation of ore bodies; and the features of ore deposits. This general part of the subject takes up the first fifty pages, and most of the rest of the volume treats of different kinds of ore deposits and

other deposits of economic value, including iron, chromium, manganese, copper, tin, cobalt and nickel, zinc, lead, silver, gold, platinum group, tungsten, molybdenum, antimony, bismuth, cadmium, arsenic, mercury, precious stones, coal, graphite, petroleum, natural gas, ozokerite, asphalt, salt, soda, borax, niter, soda niter, barytes, sulphur, iron pyrites, feldspar, fluorite, mineral pigments, abrasives, marble, limestones other than marble, building stones in general, kaolin, clay, bauxite, aluminum, glass sand, refractory materials, natural fertilizers, monazite, road materials, soils and water. Under each of these headings is given a brief account of the chemical and mineralogical character of the material under discussion, its mode of occurrence, its distribution, and other technical or commercial data of interest, together with a list of the more important literature on the subject. The volume closes with a few very pertinent remarks and suggestions on the subject of reports on mining properties, and with a list of references to works on mining law.

The lists of literature given in the volume contain the more important publications on the different subjects treated, and though, as the authors themselves say, they have not attempted to make the bibliography complete, yet the references which they have given are all useful and will be found to be a ready guide to those who wish to follow up the subject further. For the student, this system is especially useful, as he gets in the syllabus only references to the most important literature, and is not encumbered with what is not immediately necessary for his purposes; at the same time he has the means of finding any other literature that may exist on the subject. A very useful feature of the volume are the blank pages which alternate with the pages of printed matter, thus giving means of inserting further references to literature or making short notes, etc.

The volume contains 141 illustrations including geological sections, sections of ore bodies and of mines, statistical tables, etc., all of which add greatly to the usefulness of the work as they make it possible in a condensed form to understand clearly the various subjects discussed.

The volume relates mostly to the economic geology of the United States, but that of foreign countries is occasionally mentioned. It covers a wide field in a form which though condensed is sufficiently full to answer all the purposes for which it is intended. It is a most valuable work, and the thanks of all interested in economic geology are due to the authors who have prepared it. R. A. F. P., Jr.

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METHODS OF STUDYING EARTHQUAKES

I PROPOSE in this paper to consider the methods of studying earthquakes of a moderate degree of intensity, *i. e.*, those which disturb areas of not more than a few thousands of square miles, and which as a rule are too weak to cause any very serious damage to property. Of such earthquakes, about ten or twelve are felt every year in Great Britian; the majority are slight, but once in four or five years a shock will occur that is noticed over a district containing more than 50,000 square miles. The methods of investigation do not, however, vary much in these cases; but, as they can only be applied with success in rather populous countries, it seems possible that they may be as useful in certain parts of the United States as they have already proved to be in the British Isles.

The whole aim of an earthquake inquiry has been widened during the last ten years. It is no longer merely a question of determining the position of the epicenter, though this is still one of the first problems to be solved. We have to ascertain not only the place where a fault-slip occurred, but the direction of the originating fault, its hade, and the nature of the movement which gave rise to the shock; for the earthquake is but a passing incident in the growth of a fault. It is the transitory effect on the surface of a displacement, within the earth's crust; and

the displacement, rather than its effect, is the more impor subject for investigation.

For determining the position of the epicenter, three meth have been employed, depending respectively on observation the direction, time of occurrence, and intensity of the shock.

The first method was suggested by Mallet, and used by in studying the Neapolitan earthquake of 1857, and by a other seismologists who have followed in his steps. Later on, method fell into disrepute; and, so far as it depends on indivi observations of the projection or fall of bodies, etc., it mu think, be regarded as unreliable. But, if the number of obse tions be large, the average of all the records in one place give a close approximation to the true direction. This was shown by Professor Omori for the Tokio earthquake of 1894. that city, the earthquake, besides a number of minor vibrati consisted of a single great oscillation, the maximum displacem in which was 73^{mm} in the direction W. 20° S. and E. 20° Many columns and monuments were overthrown, and especi a large number of "Ishidoro" or stone lamp-stands place gardens. Professor Omori measured the directions in which bodies fell in different parts of the city, 144 being "Ishido with circular bases. The directions are extremely varied, an first sight appear to be subject to no law, but the mean direc given by all the observations is W. 19° S. and E. 19° N.[1] If take only the 144 "Ishidoro" with circular bases, and regard the determinations of the direction as of equal value, we find mean direction to agree exactly with that given by the seis graphic record, and to have a probable error of less than degrees.

The study of the Hereford earthquake of 1896 led to a so what similar result. In this case, observations of overtur bodies were not available, and the estimates of the direction w all made from personal impressions. They are extremely rou few of the observers referring to more than the eight princi points of the compass. Moreover, as a general rule, the appar

[1] Bull. della Soc. Sismol. Ital., Vol. II, 1896, pp. 180–188.

direction of the movement was nearly perpendicular to one of the principal walls of the house in which the estimate was made. But this very fact, which seems to render the observations valueless, turns out to be of service; for the impression of direction is most distinct in buildings whose walls are perpendicular to the true direction of the shock. The majority of the records naturally come from such houses, and thus the average of all the estimates collected gives a nearly accurate result. The mean directions for London and Birmingham, for instance, intersect almost exactly in the epicenter, and those for several counties pass within a short distance of this spot.[1] Thus the method of directions, if we give a somewhat different meaning to it from that intended by Mallet, may determine the position of the epicenter with a close approach to accuracy.

It is doubtful whether the second method, depending on time-observations, can ever lead to any but very rough results. The chief reason for this is the difficulty of determining the time accurately to within a few seconds. But, supposing this were possible, there is also the uncertainty whether it is the same phase of the motion which is timed by observers in different places; for the vibrations which appear strongest to different persons do not necessarily come from the same part of the focus, and may come from parts which are separated by a distance that is considerable when compared with the dimensions of the disturbed area. While good time-observations may enable us to determine the surface velocity of the earth-wave, they can hardly, unless very numerous, afford information of much value with regard to the position of the epicenter, and still less with regard to the depth of the focus.

There remains the third, and by far the most fruitful, method of inquiry — that which is founded on the intensity of the shock.

[1] "The Hereford Earthquake of 1896" (Cornish Bros., Birmingham,) pp. 265–270. I have applied this method to the Charleston earthquake of 1886, for which Captain Dutton's well-known memoir supplies the materials. Here it was necessary to group together observations in separate states, the areas of which are to large to give good results. But, in several cases, the mean direction so obtained differs only by a few degrees from the line joining the center of the state to the epicenter.

By means of an arbitrary scale, for which we are indebted tc joint labors of Professors M. S. de Rossi and F. A. Forel, intensity at any place may be expressed according to mechanical effects produced by the earthquake. A series of seismal lines may then be drawn, each surrounding the pl where the shock was of a given intensity and excluding t where it was distinctly less; and if the series is complete, innermost isoseismal enables us to determine the position of epicenter, generally with a close approach to accuracy.

But the method of intensities does more than this. Wher isoseismal lines are carefully drawn—and this is only pos roughly elliptical in form; their longer axes are paralle nearly so, but they are not coincident. In my report on Hereford earthquake (pp. 216–218), it is shown that this ı be the case when the earthquake is due to the friction gener by a fault-slip; for the focus is then a surface inclined to horizon. Moreover, the focus and relative positions of the seismal lines are indices of the direction and slope of the f plane. The longer axes of the curves are parallel to the fault or strike of the fault; and, on the side toward which the slopes, the isoseismal lines are further apart than on the c side of the fault-line, except at great distances in the case strong earthquake, when the inequality is reversed.

I can give no better example of a slight earthquake than which occurred on April 1, 1898, in the south of Cornwall.[1] positions of the principal places where it was felt are show Fig. 1, but the coast-line is omitted in order to simplify diagram. The continuous curves represent the isoseismal of intensities 4 and 3 of the Rossi-Forel scale; and their f and relative position show that the fault-line must run ı E. 33° N. to W. 33° S., and that the fault must hade tc southeast.

The latter inference is corroborated by the study of sound-phenomena, to which the two dotted lines relate. outer of these lines represents the boundary of the sound-a

[1] Quart. Jour. Geol. Soc., Vol. LXVI, 1900, pp. 1–7.

while the inner one separates those places where the sound was loud from those where it was distinctly fainter. As the more prominent sound-vibrations appear to come from the upper margin of the seismic focus[1], the northwesterly shift of the sound-curves with respect to the isoseismal lines implies that the fault hades in the direction opposite to them.

One of the most interesting features of British earthquakes, though it is by no means confined to them, is the double nature of the shock. At many places there are two distinct series of vibrations separated by a brief interval of absolute rest and with a large number of observations—they are as a rule quiet. This was the case during the Hereford earthquake of 1896 nearly all over the disturbed area. As a

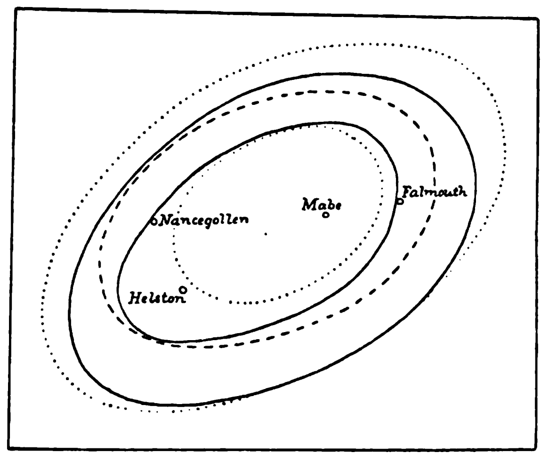


FIG. 1.

rule, however, a weak tremor and a faint rumbling noise are observed during the interval at places near the epicenter; while at considerable distances from the origin these become imperceptible, and the shock appears to consist of two detached portions. The double shock is chiefly characteristic of strong or severe earthquakes but there are several slight ones in which it has been observed. Attempts have been made to explain it by the reflection or refraction of the earth-waves at the bounding surfaces of strata, or by the existence of longitudinal and transversal vibrations. But the wide distribution of the places where the double shock is observed and the fact that the relative nature of the two parts of the shock is not constant all over the

[1] Phil. Mag., Jan. 1900, pp. 66–70.

disturbed area, are conclusive against any theory based on the assumption of a single initial impulse. In the cases which have been investigated, there can be no doubt, I think, that there were two distinct foci, and that the impulses at them were nearly, but not quite, simultaneous. In the Charleston earthquake of 1886, Captain Dutton was able to locate the two foci; and this has also been done in several British earthquakes.

There appear, however, to be two distinct classes of earthquakes in which a double shock is observed; of which the Cornish earthquake of 1898 and the Hereford earthquake of 1896 may be regarded as respective types. The chief outward difference consists in the length of the interval between the two parts of the shock. In the first case, the interval was a quarter of a minute or more in length; in the second, it varied from a few seconds to zero. The Cornish earthquake consisted in reality of two successive earthquakes originating in nearly the same region of the fault, and the foci were overlapping. The Hereford earthquake was a true *twin* earthquake, the foci were completely detached; but the impulses at the two foci were due to the same initial stress, and the impulse at the second was in no way a consequence of that at the first, for it took place before the earth-wave from the first had time to reach the other.[1]

The two parts of a twin earthquake differ as a rule in intensity, in duration, in the period of their vibrations, and possibly in other ways. The distribution of the places where the first part was stronger, etc., than the second, enable us to determine at which focus the initial impulse was the more powerful and which was first in action. In the Hereford earthquake, the region in which the first part of the shock was stronger, of greater duration, and consisted of slower vibrations, was separated from that in which the same features characterized the second part, by a hyperbolic band, passing between the two foci. Within this band the

[1] The explanation of the double shock given in the report on the Hereford Earthquake (p. 295) I believe to be generally true for twin earthquakes; but I propose to consider the subject more fully in another paper.

two parts of the shock were superposed, showing that the impulses were not simultaneous, and that the focus within the concave part of the hyperbola was last in action. In the Cornish earthquake of 1898, the interval between the two parts of the shock was so great that the first and weaker part was felt all over its disturbed area before the second was felt at its epicenter. Consequently, the broken line in Fig. 1, which surrounds all the places where the double shock was observed, constitutes the boundary of the disturbed area of the earlier portion.

In studying an earthquake, there will be found on almost every point considerable conflict in the evidence collected. Much of it is no doubt due to inaccurate observation, part to a misunderstanding as to the information desired. It is in the records of the sound phenomena that the greatest diversity exists, a diversity which can hardly be ascribed to inattention or defective observation, and which can only be explained completely on the supposition that the sound is so deep that some persons are incapable of hearing it. Near the epicenter, the strength of the sound-vibrations is so great that they are audible to nearly every person, but the percentage of observers who hear the sound decreases rapidly towards the boundary of the sound-area. The variation in audibility throughout the sound-area may be illustrated by means of isacoustic lines. The percentage of auditors of the sound among those observers within a given area who felt the shock is taken to correspond to the center of the area in question, the lines joining adjacent centers are divided so as to give points where the percentage would, on the hypothesis of uniform variation, have certain definite values, say 90, 80, 70, etc., and lines are drawn through all points where the percentage marked is the same. The isacoustic lines for the Hereford earthquake of 1896 are represented in Fig. 2. The axis of the isoseismal lines runs almost exactly northwest and southeast, and the points of greatest extension of the isacoustic lines lie on a curve (broken in the figure) which coincides almost exactly with the hyperbolic band referred to above. The explanation of the peculiar distortions of the isacoustic lines is that, along this band, the

sound-vibrations from both foci were heard simultaneously, and the additional strength thus rendered them audible to an increased percentage of observers.[1]

The variation of other phenomena may be similarly represented — such as the frequency of comparison of the sound to

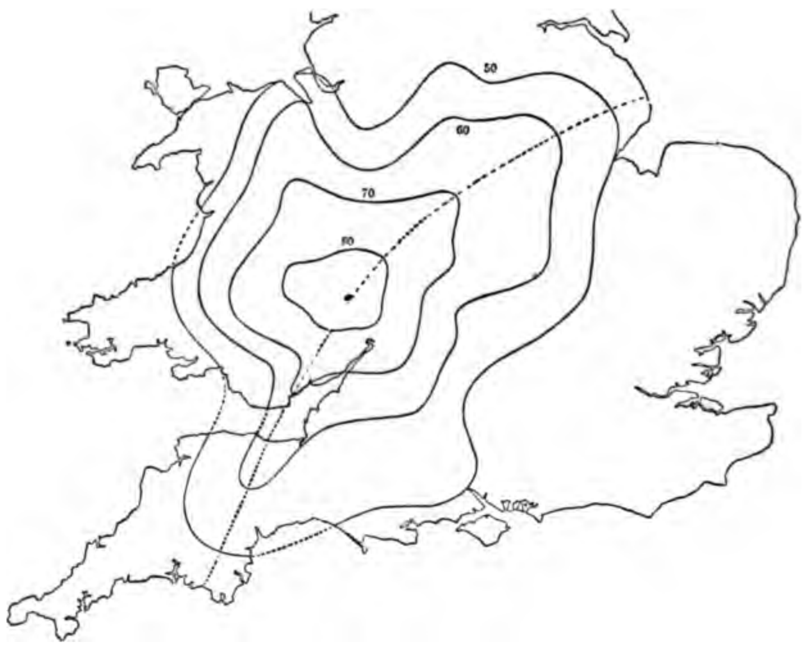


FIG. 2.

definite types, the audibility of the sound-vibrations before and after the shock is felt, the audibility of the loud crashes heard when the sound is loudest, etc. The method of course requires a very large number of records for its employment; but, in no other way, can the influence of erroneous or defective observations be so successfully eliminated.

CHARLES DAVISON.

KING EDWARDS HIGH SCHOOL.

[1] Phil. Mag., Jan. 1900, p. 43.

GLACIAL GROOVES AND STRIAE IN SOUTHEASTERN NEBRASKA[1]

NEBRASKA is so close upon the western as well as the southern limit of the drift that evidences of glacial action which might be commonplace elsewhere are rare and interesting here. The mere fact that glacial grooves and striae have been found seems worthy therefore of mention. Glacial drift, readily recognizable as such, does not extend far west of the 97th meridian, and in but one place in the state, on the Dakota-Nebraska boundary, does it reach the 98th meridian. East of the 97th meridian it is distinct and unmistakable, and it may be offered as a safe statement that probably in no other state is the glacial drift so generally recognized as such by the mass of the people. This is due to the presence of numerous bright red and purple bowlders of Sioux quartzite. They are unmistakable, and it is generally known that they have been transported from the region of Sioux Falls in South Dakota, and scattered along the eastern border of Nebraska, and south into Kansas. Bowlders of Sioux quartzite twenty feet in diameter are to be found as far south as the Nebraska-Kansas line. A heavy mantel of drift, overlaid by a hundred feet or so of loess, so effectually conceals the rocks that exposures are rare, and striations and similar evidence of glacial action, which may be common enough in fact, are not seen. The first were found by the author in 1894 on a slab of Carboniferous limestone in the old Reed quarry one mile northeast of Weeping Water.

Though not found exactly in place it was unmistakably native rock. The ledge from which it came has just been found by Mr. E. G. Woodruff (Univ. Nebr. 1900). It is a narrow ledge perhaps 300 feet long by five to six feet wide, leveled, smoothed, and striated throughout. The grooves and striae run south eleven degrees east. One groove, the most conspicuous

[1] Paper read before the Nebraska Academy of Science, December 2, 1899.

... Weeping Water, Nebraska, ... and grooves. The central ... one and one quarter ... the writer.

... a quarter deep, ran ... numerous ragged ... inch in depth, and ... The whole surface ... were well polished. ... of a little clay, ... bowlder of Sioux

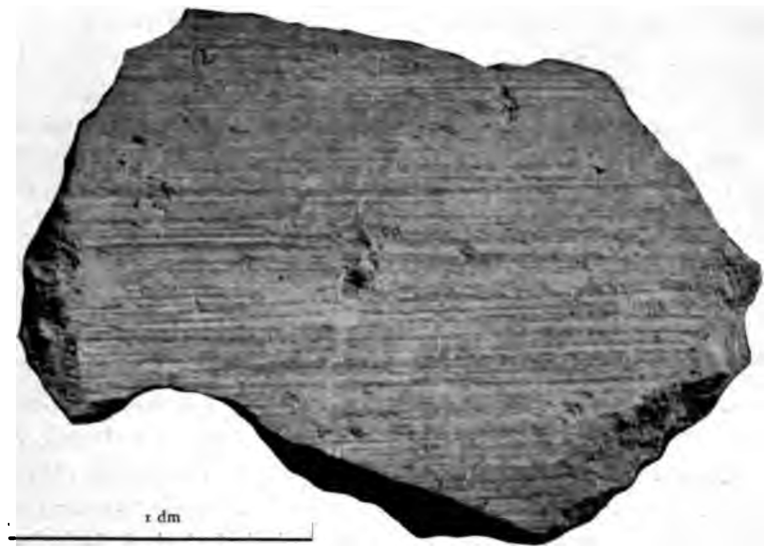


FIG. 2.—Cabinet specimen (7 by 10 in.) in the State Museum of Nebraska, showing planed surface and glacial striae on carboniferous limestone, Weeping Water, Nebraska. Striae run south 11° east. Photograph of a specimen procured by the writer in 1894.

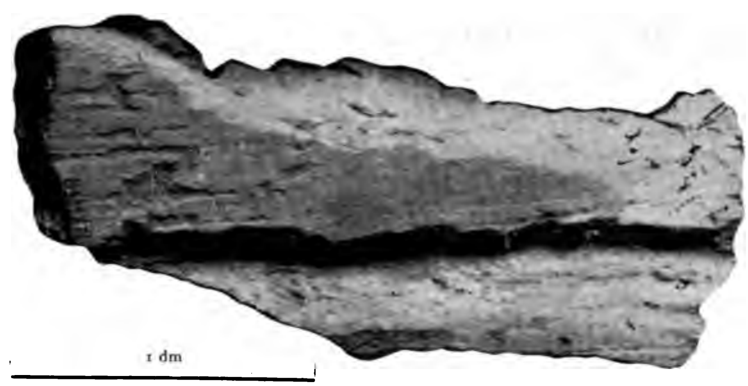


FIG. 3.—Cabinet specimen (7 by 10 in.) in the State Museum of Nebraska, showing planed and polished surface, striae, and a small glaciai groove, carboniferous limestone, Weeping Water, Nebraska. Photograph from a specimen secured by Mr. E. G. Woodruff, fall of 1899.

quartzite, the largest noted being about three feet through. The drift is thin here, nowhere exceeding a foot or two, as far as observed. Upon this thin but unmistakable layer of drift lies some twelve to fifteen feet of loess.

Two very tortuous miniature channels with polished and scored sides were noted. The curves were so abrupt that the striating and polishing must have resulted from the action of streams of glacial mud and gravel being under stress and driven with unusual force through the confined and winding channel.

This seems to be the point farthest south in the state where such grooves and striae have been noted. At La Platte light grooves and striae have been reported in the Carboniferous limestone. In the Dakota Cretaceous near South Bend, Mr. Charles N. Gould has observed parallel grooves which may be glacial, or as he thinks more likely artificial, being made by the Indians in former times when sharpening implements in the sandy rock of this formation. In the spring a considerable area at Weeping Water will be stripped of the overlying drift and loess, at which time it can be examined to much greater advantage than now.

ERWIN HINCKLEY BARBOUR.

THE UNIVERSITY OF NEBRASKA.

A NOTICE OF A NEW AREA OF DEVONIAN ROCKS IN WISCONSIN

THERE is an outcrop of Devonian rock on the shore of Lake Michigan in this state, ten miles north of Port Washington and about a mile southeast of the little village of Lake Church, which has hitherto escaped the notice of geologists. The discovery of this exposure by the writer in the summer of 1896 was somewhat of a surprise as all the nearest outcrops of rock, to the north, south, and west, belong to the Niagara formation. In the neighborhood of Lake Church the heavy drift deposits, which form high bluffs on the very edge of the lake at Milwaukee and at Port Washington, recede quite a distance from the shore and take the form of a series of rolling ridges which increase in height towards the west. Between the lowest of these ridges and the lake there stretches a sort of terrace, elevated only five or six feet above the lake level at its eastern margin and rising very gradually as it recedes from the shore. The rock in question forms the floor of this terrace and crops out in various places in the neighborhood upon the beach and under the water. It is also uncovered in the bed of a little watercourse which traverses the terrace. The strata are nearly level but probably dip slightly towards the east. The rock is an impure limestone, somewhat earthy in composition and somewhat granular or sandy to the touch. An inconsiderable excavation has been made in it by the owners, disclosing a thickness of about six feet of Devonian strata, beneath which is a transition layer of bluish shaly rock, resting on a very hard, white, crystalline limestone which probably belongs to the Niagara.

About sixty species of fossils have been obtained from the upper layers, all of which, with the exception of a single fragmentary dental plate of Rhynchodus, are in the form of casts and impressions, a fact which renders their determination a matter of some difficulty. The fauna comprises about twenty-four

species of brachiopods, twelve or thirteen of gastropods, nine corals and half a dozen pelecypods. *Orthoceras*, *Rhynchodus*, and *Proëtus* are each represented by a single species; there are scattered crinoid joints and a few other species whose generic relations, even, have not yet been satisfactorily determined.

Among the most abundant species are: *Chonetes scitulus* Hall, *Stropheodonata nacrea* Hall, *Atrypa reticularis* L. and a species of *Spirifer* with a marked depression in the fold of the brachial and a remarkably broad and strongly impressed muscular area in the pedicle valve. Two or three other species, both of *Spirifer* and of *Stropheodonta*, are apparently represented. *Stropheodonta demissa* Conrad is probably one of the latter; another is a strongly arcuate form, with a thick shell and an almost smooth surface. Among other species which have been identified are *Cyrtina hamiltonensis* Hall (rare), *Orthis impressa* Hall (a single specimen), *Atrypa spinosa* Hall, *Productella spinulicosta* Hall, and *Conocardium cuneus* Conrad (the three last fairly common). There is also a species of *Athyris;* one of *Meristella;* a *Cyclonema*, near *C. multilira* Hall; two species of *Loxonema* of ordinary form; a tapering *Turritella*-shaped shell, with both revolving and transverse striae, resembling but not identical with certain forms occurring in the Devonian of Manitoba and referred by Whiteaves to the genus *Loxonema;* a *Murchisonia*, near *M. turbinata* Schlotheim; a *Trochonema*-like shell with strongly angular and nodose revolving ridges; a *Bellerophon*, near *B. pelops* Hall or *B. newberryi* Meek; a *Paracyclas* and a *Mytilarca*. Among corals are a species of *Streptelasma;* one of *Zaphrentis;* one of *Acervularia* and another of an allied genus; and a species of *Favosites*.

The rock in which this fauna has been discovered is thought to constitute good material for road-making. A more extensive development of the quarry, which it is hoped will take place before long, will furnish opportunities for more satisfactory investigation of the fossils.

CHARLES E. MONROE.

MILWAUKEE, WIS.,
April 25, 1900.

KINDERHOOK STRATIGRAPHY

At frequent intervals during the past decade, there have appeared notes on certain beds, occurring in different parts of the Mississippi valley, which have passed under the general name of Kinderhook. For the most part these notes have dealt with local phenomena. In the present connection attention is called briefly to some problems of broader significance.

Along the upper Mississippi River the formations immediately underlying the great Burlington limestones are exposed chiefly in two localities. One is at Burlington, Iowa, and the other at Louisiana and Hannibal, Missouri, and at Kinderhook, Illinois, which is only a few miles from the last named place. Between the two localities the distance is 125 miles. In this distance a shallow syncline carries down the Kinderhook beds 200 feet below the level of the stream.

The early investigations of this Burlington-Louisiana section were carried on simultaneously at the two ends, but by different persons. When the time came to parallel in detail the vertical sections at the extremes difficulties arose. The various beds could not be traced from one point to another because, for most of the distance, the strata were not open to inspection. The method of correlation by visible continuity was inapplicable. Comparison by similar lithologic sequence was likewise unsatisfactory, because the sections were so very different, and it was impossible to tell when or in what manner the changes took place.

When the fossils of the two localities were compared, the results were singularly futile, so far as throwing light upon the problem of exact stratigraphic equivalency. The organic forms were unequally distributed. A large part of both sections had yielded no fossil remains at all. In the northern locality the known animal remains had been found chiefly at the very top

of the section; in the southern, at the very bottom. As to the exact horizons of their occurrence the literature usually gave small clew. With most of the forms no comparison was possible, for the facies of the two faunas were of very different types. After an elapse of 30 years the question of the geological age of the various beds presented itself as formidably as when first these rocks were brought into notice.

Of late years a number of deep wells have been drilled along the upper Mississippi River. These have enabled various geological sections exposed at points far removed from one another to be connected with a degree of confidence never before attained. In the Louisiana-Burlington cross-section, wells at Hannibal, La Grange, Keokuk, Burlington and other points have disclosed important features. These purely stratigraphical features are of particular interest at the present time because of their bearing upon the lack of geological integrity of the typical Kinderhook.

On all of the problems mentioned, the data derived from the deep-well sections have an important bearing. Furthermore, it is pointed out just along what lines critical evidence is to be sought.

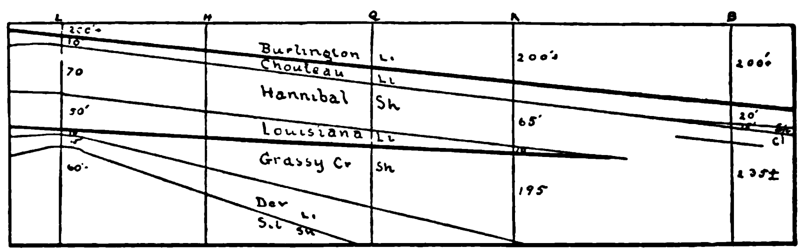
A few years ago the geological sections at the type localities of the several parts making up the Mississippian series of the Carboniferous, were personally studied in order to find out from first hands just what each really meant.[1] Among these sections were those found in the vicinity of Kinderhook, Illinois, which were the basis of what had been long considered the lowermost member of the Carboniferous system, and had been widely known as the Kinderhook formation. Hannibal and Louisiana, Missouri, which are not far away, exhibited the same rocks even to better advantage, and therefore were regarded in all respects as essentially typical.

As is well known, the typical Kinderhook has been regarded as consisting of three members: A basal Louisiana limestone, a median Hannibal shale, and a capping Chouteau limestone.

[1] Principal Mississippian Section; Bull. Geol. Soc. America, Vol. III, pp. 283-300, 1892.

These three members retain their lithological characteristics over broad areas, the extent of which is surprising. The distances of continuity are so great that ordinarily doubt would be cast upon this assumption were it not for the fact that all observations are easily checked by the overlying Burlington limestone. While the lithological features of the several parts of the Kinderhook are so persistent, the faunas contained appear to be remarkably local in nature. The existence of a large number of restricted faunas, in place of a general one is probably the chief cause for past failures to correlate, by the biotic method, the various sections of the Kinderhook.

The stratigraphical relationships of the Burlington and Louisiana sections at last appear to be indicated by the aid of the deep wells drilled between the two points. These relationships are best expressed by the following diagrammatic cross-section, in which, however, while drawn to a scale, no allowance is made



for the synclinal attitude of the strata. What has been regarded as the typical Kinderhook formation is included between the heavy lines.

Immediately beneath the Louisiana limestone, the basal member of the Kinderhook at Louisiana and vicinity, is the Black shale of the Devonian, according to Meek and Worthen.[1] In the neighborhood of Louisiana it has been called the Grassy Creek shale.[2] While at the town itself it only has a thickness of about six feet, and thins out completely to the south, it is 30 feet thick on Grassy Creek, a few miles to the west. Northward,

[1] American Jour. Sci. (II), Vol. XXXII, p. 228, 1861.

[2] Proc. Iowa Acad. Sci., Vol. V, p. 63, 1898.

this shale bed grows rapidly in thickness, until at Keokuk it reaches 195 feet.

The Louisiana limestone, which is over 50 feet thick at the type locality, appears to get thinner northward. At Keokuk it is only 10 feet in thickness, and seemingly fails altogether before Burlington is reached. Its southern extension is not known. It is not believed to be as extensive as Missouri geologists have generally supposed. The Lithographic limestone of southwestern Missouri is not thought to be the same. The apparent fading out towards the north is not an unusual phenomenon among the limestones of the region. Similar cases are known in the Missourian series, or Upper Coal Measures, farther west.[1]

At Louisiana and Hannibal, the shales bearing the latter name have a thickness of about 70 feet. This thickness is maintained northward at least as far as Keokuk, as deep wells show. Beyond this point at Burlington a very similar shale, appears in the base of the river bluffs, having a thickness, including the upper sandy portion (Chonopectus sandstone of Weller[2]), of 85 feet, above the river level. Shale is known to extend downward at least 150 feet more, making a total measurement, from the top of the Chonopectus sandstone, of 235 feet.

The question has arisen as to how much of the Burlington section[3] can be regarded as representing the Hannibal shale. On fancied lithologic grounds solely it was early suggested by Worthen[4] and White[5] that the earthy fragmentary limestone, 15 to 18 feet thick, overlying the lower "yellow sandstone" (the Chonopectus bed) was the northern extention of the lithographic (Louisiana) limestone of Missouri. This view has been recently again alluded to by Weller.[6] If this were the case all

[1] Proc. Iowa Acad. Sci., Vol. VII, 1900.

[2] Trans. Acad. Sci., St.Louis, Vol. X, p. 57, 1900.

[3] Full detailed descriptions of the various sections here referred to will be found in the lately issued volumes of the Iowa and Missouri geological surveys.

[4] Geology Iowa, Vol. I, p. 206, 1858.

[5] Boston Jour. Nat. Hist., Vol. VII, p. 212, 1860.

[6] Trans. Acad. Sci., St. Louis, Vol. X, p. 123 1900.

of the Burlington section below the top of the Chonopectus sandstone would be beneath the horizon of the Louisiana limestone.[1]

In the recent Iowa[2] and Missouri[3] reports the basal shale as exposed above river level at Burlington was considered as about the equivalent of the Hannibal shale. At the same time it was surmised that this part of the section at Burlington probably rested directly upon certain shales found farther north, and which were commonly regarded as belonging to the Devonian. This, however, was merely a working hypothesis; and opportunity did not present itself to carry out very far the necessary field investigation to either prove or disprove it.

On this supposition the 235 feet of shale, of which about one third is above the river level at Burlington, would represent not only the Hannibal shale, but in its lower unexposed part, a so-called Devonian shale as well. The recent discovery of a rich fauna[4] considered as composed of typical Devonian types gives strength to this idea. Still later Weller[5] gives expression to something of the same conception when he states regarding the occurrence of the Hannibal shales in Iowa, that it is "probable that the section at Burlington is equivalent, or more than equivalent, to the whole of the section as known in Missouri." If we take into consideration the 150 feet of shales below water level the stratigraphic evidence now presented goes far towards proving the statement.

The deep-well sections give no indication that the Hannibal shales, as they are known at the type locality, change materially either stratigraphically or lithologically from Louisiana to Keokuk. There is yet no reason whatever for imagining that they should abruptly thin out entirely between Keokuk and Burlington.

[1] Iowa Geol. Sur., Vol. X, p. 79, 1900.

[2] Iowa Geol. Surv., Vol. I, p. 55, 1893.

[3] Missouri Geol. Surv., Vol. IV, p. 56, 1894.

[4] Proc. Iowa Acad. Sci., Vol. IV, p. 39. 1897.

[5] Trans. Acad. Sci., St. Louis, Vol. X, p. 123, 1900.

One the other hand, all evidence goes to show that the Louisiana limestone gradually becomes thinner as the distance increases from the type locality northward, until at Keokuk it is less than one fifth of its original thickness. Everything indicates that it has faded out completely long before the city of Burlington is reached. If the Hannibal shales have retained anything of their normal thickness, as they have in the long distance from Louisiana to Keokuk, the horizon of the Louisiana limestone would be expected to be not far above the river level at Burlington. No bed at or near this horizon has been found that would correspond in lithological or any other of the characters of the Louisiana formation. The only layer of the whole Burlington section below the base of the Burlington limestone, that at all resembles the Louisiana is the Productal limestone (No. 3 of Keyes, No. 4 of Weller), with a coralline zone at the base (No. 3 of Weller), and overlying the Chonopectus sandstone. The lithologial characters of the two are only remotedly related. There are strong stratigraphic reasons, however, for connecting this stratum, as well as those above it, up to the Burlington limestone, with the Kinderhook limestones still farther north at LeGrand, in Marshall county, Iowa. Still other grounds exist for believing the Productal zone at Burlington to be the attenuated margin of LeGrand beds.[1]

All the stratigraphic evidence, as disclosed by the Mississippi River cross-section, the deep wells along the course, and the general geological features of the region appear to indicate, beyond much doubt, that the Louisiana limestone actually does become attenuated northward from the type locality, and that the underlying Grassy Creek shales and the overlying Hannibal shales merge north of Keokuk. If this be the correct interpretation, the section at Burlington, below the top of the Chonopectus sandstone, including over 100 feet of shales beneath the river level, represents considerably more than the Hannibal shales of Missouri.

[1]There is, therefore, apparently little possibility of the Productal limestone representing anything other than the Chouteau beds as exposed farther south.

The Chouteau limestone, which finds its typical development in central Missouri, appears to be well represented, in the northeastern part of the state where the typical Kinderhook is shown, by 10 feet or more of massive earthy limestone, that is fine grained and contains comparatively few fossils. It is sufficiently distinctive in lithological characters to be readily recognizable in deep-well drillings. At Keokuk, it is over 20 feet thick, and at Burlington, if we consider the interval between the Chonopectus sandstone and the Burlington limestone as representing it, about 30 feet thick. In central Iowa it is believed to be represented by the LeGrand limestone, and is over 100 feet thick, there being about the same development as in central Missouri.

The lithologic features at Burlington, while differing from those farther south and at the type locality in central Missouri, correspond very closely with the characters presented northward. At Burlington, also, it is still chiefly limestone. Here it consists of a thin basal coralline zone, the Productal limestone, the Spirifer sandstone, the Gyroceras oolite and the brown Rhodocrinus limestone. These, however, are local collectors' names, and it is not known how far these distinctions should be really recognized.

Independent of the purely stratigraphical characters of the Kinderhook, as exposed along the Mississippi River, there are certain faunal features of the formation that are not without interest. Until now, all correlations of the Kinderhook beds have had to be inferred from imperfect fossil data. Moreover, the information has been so inexact for present requirements, that the fossils have to be studied largely anew in order to find out in just what layers the various forms occur. Only in this way can useful and exact comparisons of the faunas be made.

Already Weller has begun, along the lines indicated, a series of "Kinderhook Faunal Studies." Judging from the two installments already issued it is expected that there will soon be available much of the long desired information concerning the exact stratigraphic range of the fossils, and the relationships of the various biotic groups.

CHARLES R. KEYES.

ON THE PROBABLE OCCURRENCE OF A LARGE AREA OF NEPHELINE-BEARING ROCKS ON THE NORTHEAST COAST OF LAKE SUPERIOR

IN a recent paper in this JOURNAL,[1] Dr. Coleman has described, under the name of *Heronite*, an interesting analcite-bearing rock from near Heron Bay, on the northeast shore of Lake Superior, and states that although the occurrence of a dike rock of this composition would indicate the presence of nepheline syenite in the vicinity, no area of this rock had as yet been discovered in that district. Many years ago, while looking over some of the rock collections in the museum of the Canadian Geological Survey, at Ottawa, my attention was attracted by two specimens of a rather coarse-grained, red rock from Peninsula Harbor, Lake Superior, on account of the fact that their appearance suggested that they might belong to the class of nepheline syenites. Sections were made and examined at the time, but no nepheline was found, and the investigation was not carried further owing to lack of material and absence of information as to the exact mode of occurrence of the rock in question.

In connection with Dr. Coleman's paper, however, it may be well at this time to present a few notes concerning these rocks, as they indicate that the district in question affords a field of much interest for petrographical study.

The first of the rocks in question was collected by Dr. Selwyn in 1882, and is labeled "Peninsula Harbor," while the second was collected by Mr. Peter McKellar in 1870, and is labeled "Mount Point, S.E. side, Peninsula Harbor." They both come, therefore, from the same neighborhood, and probably from the same mass. Unfortunately, the specimens cannot at present be found, so that it is necessary to base the descriptions on the four thin sections in my collection.

[1] JOUR. GEOL., Vol. VII, No. 5.

The first of these rocks belongs to the class of the augite-syenites, but is of a peculiar type. The augite is represented by two varieties which pass into one another. One is a purplish-brown augite, which frequently constitutes the inner portion of large individuals, and shades away into an outer border of green augite of the second variety. This green augite also occurs in separate individuals. Both varieties have high extinction angles, and the green variety is probably an aegerine-augite. In addition to the augite, a small amount of deep bluish-green and highly pleochroic hornblende is present. The single section of this rock also contains a considerable amount of a mineral which has the high index of refraction and high double refraction of olivine, and which is destroyed by acid with gelatinization.

The feldspars, which with the augites make up most of the rock, consist in part of orthoclase and in part of microperthite, and possibly anorthoclase, and usually possess a zonal structure, an outer border or rim of microperthite often surrounding an individual of orthoclase nearly free from intergrowths. Small quantities of pyrite and magnetite are also present, as also of a deep brown, almost opaque, non-metallic mineral, which is unattacked, even by prolonged treatment, with concentrated hydrochloric acid, and which is probably one of the rarer rock-making minerals.

The structure of the rock is remarkable, and entirely different from that of the ordinary augite-syenites. The feldspars are idiomorphic, and impress their form on the dark constituents, with the exception of the olivine. These latter occupy the interstitial spaces, and are penetrated by the feldspar laths in a manner suggestive of an ophitic structure. The character of the augite and hornblende, as well as the abundance of the feldspar, suggest a magma rich in alkalis.

The second specimen strongly resembles the first, but in it the hornblende replaces the augite, and is present in large amount. This hornblende is so intensely colored that in many cases it is nearly or quite opaque, but when transparent has a deep

bluish-green color and a marked pleochroism. It has a small axial angle, and resembles in general character the variety rich in ferrous iron and alkalis described from the nepheline syenites of Dungannon, Ontario, under the name of *Hastingsite*.

The feldspars resemble those of the other specimen, but there is proportionally more microperthite and a considerable amount of an acid plagioclase. Fluor spar is also present, in not inconsiderable amount, in the form of large, colorless grains.

The structure is the same as that of the former specimen, the feldspars being idiomorphic, and the dark constituents occupying the spaces between the feldspar laths.

The specimens, therefore, while not actually containing any nepheline, have the character of certain differentiation products of alkali-rich magmas, which are found associated with nepheline syenites and other nepheline-bearing rocks in other parts of the world.

In the Report of the Geological Survey of Canada for 1846-7, Sir William Logan, after describing certain "traps" of this same district, refers to what is apparently the same occurrence, as follows:

"The rock above and below is composed of brownish feldspar and black hornblende . . . . it is large-grained, and the general mass of the country constituting the Old Pic Point and Island appears to be composed of it. Fluor spar occurs as a disseminated mineral in some of the beds. Judging from fragments on the shore, there are some beds composed of white feldspar and occasional groups of orange red grains of elaeolite, the whole studded with brilliant black crystals of hornblende, forming a very beautiful rock. The general mass of these volcanic overflows weathers to a red, and from a distance may be readily mistaken for the gneiss which underlies the chloritic shales."

Although the rocks in question are here classed as belonging to the traps of the district, in the Geology of Canada published by the Geological Survey of Canada in 1863, they are, in a reproduction of the passage quoted above, referred to simply

as "igneous rocks" and nothing is said about their supposed volcanic affinities. In the same publication also, p. 467, the occurrence is referred to as follows:

"On the main shore of Lake Superior, nearly north of the western extremity of Pic Island, is a mass of syenitic rock, composed of red feldspar and hornblende, with zircons which resemble the zircon syenite of Norway." As is well known, this latter rock is an augite-syenite, which in Norway is intimately related to nepheline-syenite.

As all the localities mentioned in this note are near one another on the same stretch of coast, and in the vicinity of Heron Bay, it seems certain that there is in this district a large intrusion of an alkali-rich magma, differentiated into various rock facies, among which there are some containing nepheline and some free from that mineral, and that Dr. Coleman's Heronite is connected with the intrusion in question.

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A NOTE ON THE LAST STAGE OF THE ICE AGE IN CENTRAL SCANDINAVIA

In the Dovre region which lies to the north of Christiania the main divide runs in an east-westerly direction. On the mountain plateaus of this region the parent rock of much of the drift is found on the southern side of the divide; consequently the ice had its movement upstream, at least during part of the ice age.

FIG. 1.—The Dovre region in Norway. The arrows mark the movement of the ice. The shaded part is the last remnant of the great ice according to Dr. Andre M. Hansen.

Dr. Andre M. Hansen has given a reasonable explanation of this fact which may be illustrated by the following diagram, Fig. 2.

The country is steeper on the north side of the divide (*a n*) than on the south side (*a s*). The contour of the ice-cover, on the other hand, formed a rather regular curve, and the movement in it took place from the thickest and highest part (*b*) outward to both sides. Consequently on the stretch (*c a*) the movement was against the slope of the surface as indicated by the largest arrow of the diagram.

Now let us leave for a moment this question of the ice movement and turn to another phenomenon. In the upper parts of the valleys to the south of the divide, strand-lines occur of the same kind as the much discussed "parallel roads"

of the Scottish Highlands. The explanation is the same in Norway as in Scotland; they are the beaches of lakes which were dammed in by ice during the late glacial time. Dr. Hansen has tried to give an elaborate account of the manner in which this came about. He thinks that the ice melted latest where the thickness was greatest, and that the last remnants came to lie as a narrow strip of ice, a sort of "ice sausage," on the slope of the south of the divide and somewhat parallel to it (see Fig. 1). On the diagram the shaded part shows the ice in the last stage, and the lakes were dammed in between it and the divide. The readers of this JOURNAL may remember that this

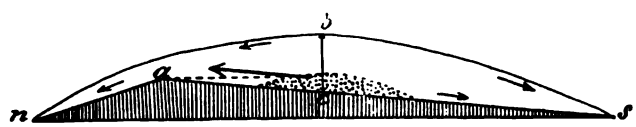

FIG. 2.

explanation was hinted at in a paper by Dr. Hansen, entitled "Glacial Succession in Norway," Vol. II, 1894, p. 137, conclusions, by the way, to which most Norwegian geologists assent only to a limited extent.

By his explanation Dr. Hansen has made urgent the question at what place the last remnants of the inland ice were located. Mr. Schiötz, professor of physics at the University of Christiania, has criticised Mr. Hansen's views from the physical standpoint in a paper entitled "How will the ice divide act during the melting of the inland ice?" printed (in Norwegian) in *Nyt Magazin for Naturvidenskaberne*, Vol. 34, Chr., 1895, pp. 102–111. He demonstrates that any "ice sausage" on the slope below the divide can come into existence only in the case that the melting takes place so suddenly and quickly that the snow line during the period of melting is at a greater height than the crest of the country. If the snow line rises gradually as the temperature rises, the diminishing glaciers will concentrate at the divide. He thinks this the most probable case, and points to the great local glaciers which undoubtedly have descended from the

divide, and to the fact that small local glaciers still exist in the region described. If Mr. Hansen is right, the snow line was first very much elevated, then descended below its present limit, and more recently has ascended again to produce the present conditions.

FIG. 3.—The Folgefonn glacier-field.

It seems to the present writer that a study of the now existing Scandinavian glaciers makes another explanation of the ice-dammed lakes more probable than that set forth by Dr. Hansen. It may be remembered that the region in question is to be regarded as a high plateau intersected by valleys. Our chief existing glaciers are also found in country of the same kind, and in accordance therewith they present themselves as gently-domed or shield-like snow-fields, intersected by valleys free of snow. This has long been known of the two great snow-fields of southern Norway, "The Folgefonn" and "The Justedalsbrae." The Folgefonn, for instance, is dissected by valleys into three parts, as seen on the accompanying map. In size the Folgefonn is the second among the Scandinavian glaciers. The greatest is the Justedalsbrae. Next to this comes "The Svartisen" (Svart = swarthy, blackish; isen = ice) situated under the polar circle. Even on our latest maps this glacier has been delineated as an unbroken elliptical snow-field with its greatest dimensions from south to north, although Mr. Rekstad of the Norwegian Geological Survey had shown in 1891 that the snow-field is divided

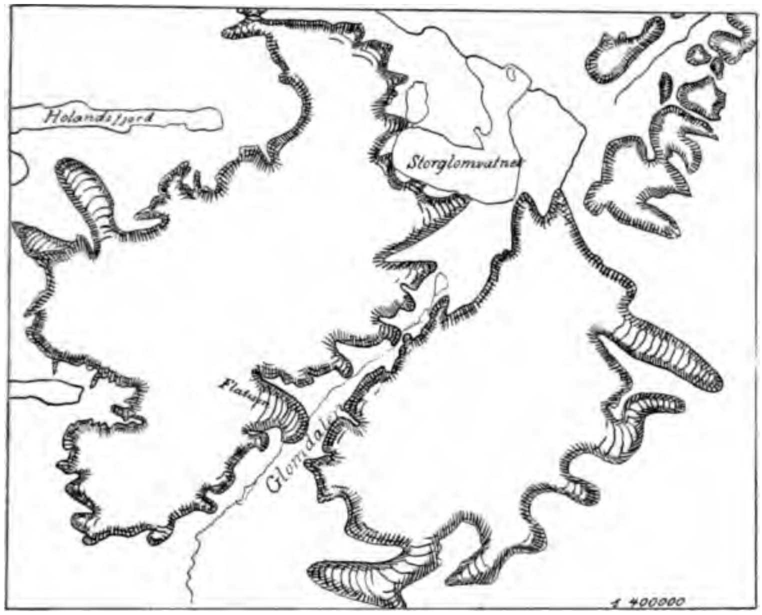

FIG. 4.—The Glacier of Svartisen.

FIG. 5.—Glaciers descending from the Svartisen to the Glomdal valley.

into two by a desert valley, the Glomdal (dal = valley). He was the first Norwegian known to have entered the inner part of that valley formerly known only to a few Laps, an incident which indicates that geographical discoveries may yet be made within Europe itself. He has described and photographed the principal

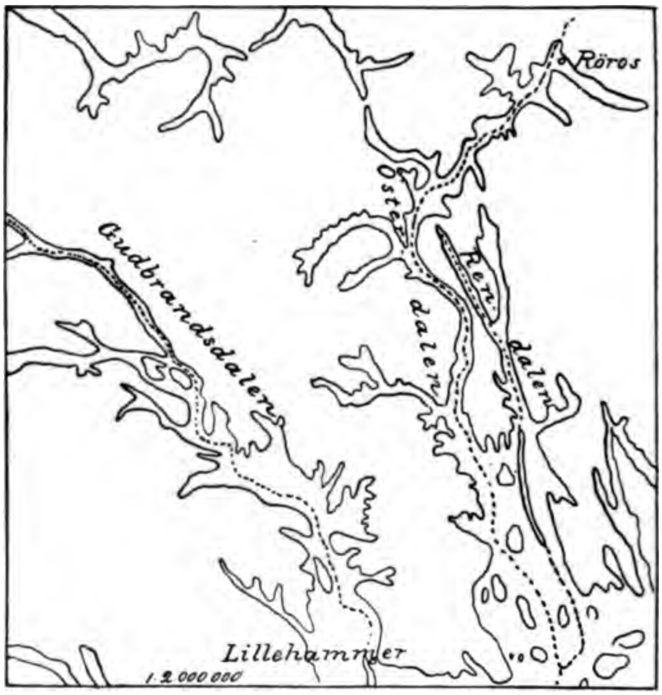

FIG. 6.—The region in the vicinity of the main Scandinavian divide to the of Christiania. The line of 100 meters above the sea is shown.

glaciers descending into the Glomdal. The greatest is pres herewith. The Norwegian Topographical Survey has o made a more detailed map of the region. With the aid o material, which has not as yet been published, the present map was made, Fig. 4.

If we now turn to the region of the old ice-damme we find a country well fitted for similar extensive field and snow, with empty valleys between. The map

shows how the line of 100 meters encompasses narrow branching valleys. We may easily imagine that during a certain stage of the melting this line was the snow line and determined the extension of the snow-fields. Some glacier descending from one of the greater side-valleys may have stopped back the water of the main valley and formed a lake. Mr. Rekstad says that the river that issues from the Glomdal valley sometimes

FIG. 7.—The Daemmevand (dammed lake) in Hardanger.

rises enormously, and that the flood is probably due to the fact that the water is temporarily obstructed by the chief glacier that intrudes upon the valley. Norway has its Märjelen See corresponding to the famous Swiss lake as is well known among geologists through Lyell's Principles. The Norwegian glacier-dammed lake is the Daemmevand (the blocked-up lake) in the province of Hardanger, in the high region to the east of the town of Bergen. From an extensive snow-field, the "Hardanger jökul" (jökul = glacier) descends to a lake. On its way it blocks up the "Daemmevand." This lake has of late attracted some attention, as the water sometimes breaks through the glacier and causes sudden and destructive floods. To prevent this the government has made a tunnel about 300 meters long

through a spur of the mountain called Turumeten. This tunnel has had the effect desired in preventing the lake rising above a fixed level. Mr. A. Holmsen, who had the supervision of the work, has had the kindness to communicate a sketch-map (Fig. 7) of the surroundings of the lake, and a photograph of the blockading glacier with a part of the lake in the foreground.

FIG. 8.—The ice barrier in front of the lake Daemme, sketched from a photograph.

From a dam like this we may mentally reconstruct a barrier capable of accounting for the lakes dammed back in olden time in the Dovre region.

There are two English accounts of this lake, viz., that of Mockler-Ferrymann ("The Daemmevand of Rembesdals Glacier Lake, *Geogr. Jour.*, IV, Dec. 1894, London, pp. 524–528) and that of Munro ("On a Remarkable Glacier Lake formed by a branch of the Hardanger-Jökul, near Eidjford, Norway, *Proc. of the Roy. Soc. of Edinburgh, Session 1892–3*, Vol. XX, pp. 53–82). The two Norwegian scientists, Bing and Öyen have also made reports on the lake.

HANS REUSCH.

STUDIES FOR STUDENTS

THE PROPERTIES OF BUILDING STONES AND METHODS OF DETERMINING THEIR VALUE. II.

In selecting a stone for building or other economic purposes, one should be familiar with the

I. Color.

II. Composition, { Mineralogical, Chemical.

III. Strength, { Crushing, Transverse.

IV. Hardness.

V. Elasticity.

VI. Porosity (including fissile planes).

VII. Specific gravity.

VIII. Weight per cubic foot.

IX. Effect of temperature changes.

(*a*) Freezing and thawing of interstitial water.

(*b*) Effect of extreme heat.

X. Effect of gases, { Carbonic, Sulphurous.

XI. Quarry conditions.

There are three important methods of obtaining these facts: (1) observations at the quarry and adjacent natural exposures; (2) examination of buildings, monuments, or other constructions built out of the stone; (3) laboratory examination. If a geologist were obliged to choose between the three, he would probably consider the first method most satisfactory. The architect and builder, on the other hand, would undoubtedly choose to examine buildings already constructed out of the stone. However, the value of opinions based solely upon quarry observations or the inspection of buildings depend largely upon the

judgment and experience of the observer. They lack a definiteness and certainty which can only be supplied by the laboratory tests. No one of these should be considered sufficient in itself, but each should be used in conjunction with the other two.

QUARRY OBSERVATIONS

Several important conclusions may result from quarry observations which cannot be reached through an examination of buildings or selected samples in the laboratory. Chief among these may be mentioned: (1) the probable injury to the stone from quarrying, handling, and dressing; (2) the capacity of the quarry to furnish as needed the required quantity of stone of the desired quality; (3) the uniformity in color and mineralogical composition, and the apparent uniformity in strength, hardness, elasticity, and porosity.

Stone is often more or less injured through improper methods of quarrying and dressing or careless handling, as explained in the previous paper.[1] One can become familiar with the methods employed in quarrying the stone only by visiting the quarry where the work is being carried on.

The knowledge that a quarry has the capacity to furnish as needed the required quantity of stone of the desired quality is an important matter. A quarry is sometimes poorly equipped with machinery; men may be scarce; orders for stone may be plentiful; and as a consequence inferior stone is placed upon the market for the better grade. The situation of the quarry in these respects can be best determined by an examination of the quarry and its equipment.

The uniformity in the color of the stone can be quickly determined by an examination of the quarry. If the stone differs in color at different horizons, or in different parts of the quarry, precautions can be taken in the specifications to insure the receipt of stone of a uniform color by designating that it be taken from a definite part of the quarry.

[1] JOUR. GEOL., Vol. III, No. 2, pp. 181–184.

Stone from different parts of the same quarry may differ widely in mineralogical composition, strength, hardness, elasticity, and porosity. Differences in these respects, when of importance, may be detected through quarry observations. However, in order to ascertain these differences, one needs to be thoroughly familiar with the conditions controlling these properties. Differences in mineralogical composition may be recognized by one who is familiar with the common rock-forming minerals.

Differences in the strength of stone result from differences in mineralogical composition, and in size, shape, and manner of contact of the individual grains, all of which can be made out by an experienced observer.

Not only can an experienced person detect differences in the qualities of stone from various parts of the same quarry, but he can also make comparisons with stone from other known localities.

At the quarry the unweathered stone can be compared with that of the natural outcrop which has been exposed to the atmosphere for many years. Comparisons based upon such observations furnish very fair estimates of the permanence of color and the degree of hardness, strength, and durability of the stone. Such estimates, however, must necessarily be very general, because of the uncertain length of time that the weathered stone has been exposed to the atmosphere. It may have been uncovered for centuries, or perhaps for only a few years.

In the outcrop the stone may be found bleached, stained with brown, or discolored with white efflorescent patches. Bleaching ordinarily proceeds very slowly and extends to no great depth, and is therefore of little importance. Brown staining usually indicates the presence of iron, and the white efflorescent patches give evidence of magnesium or calcium salts.

In glaciated regions the hardness of a rock is frequently estimated by the depth and extent to which the surface has been grooved or striated. However, this is a very uncertain evidence of hardness, being controlled largely by the condition of the

glaciers as they passed over the region in question, and the length of time that the surfaces have been exposed to the atmosphere since glaciation.

The durability of a stone is occasionally estimated from the depth to which disintegration has extended. The extent of disintegration, however, has the uncertain time element in it, which may vitiate the conclusions.

Observations on stone in the natural exposure, where disintegration has not gone too far, reveal inequalities in hardness caused by concretions, nodules, pebbles, clay seams or pockets, and fossils. Weathering also emphasizes sedimentary and jointing planes, which are obscure in the freshly quarried rock. It is often contended by quarrymen that joints die out with depth, but this cannot be laid down as a general rule. Some joints are probably superficial, but others certainly penetrate to very considerable depths. The farther the joints extend laterally, the greater is the probability that they will continue to a considerable depth.

A luxuriant growth of lichens on a natural exposure of rock is frequently taken as evidence of durability. Unfortunately this criterion of durability, when taken alone, has little significance. An abundant growth of lichens has often been observed on the surface of sandstone which was inherently soft. Such occurrences simply indicated that a crust had been formed on the exposed surface of the stone.

If one is desirous of obtaining a considerable quantity of stone perfectly uniform in color and texture, it is important that he should visit the quarry to assure himself that the amount of stone of the desired quality is obtainable. It is possible for a quarry to be exhausted of its good stone, and for this reason, an inspection is often a valuable precaution. On the other hand, the stone from a certain quarry, which has a large percentage of number one stone, may have been condemned by the public, because quarrymen and contractor have permitted the use of a few inferior blocks, "for the sake of economy." In order to know when the best stone that a quarry produces is being

received, one should be personally acquainted with the possibilities of the quarry.

OBSERVATIONS ON BUILDINGS

The inspection of constructions of long standing is generally recognized as an important means of estimating the strength and durability of stone. The value of such observations, however, is often overestimated and it frequently happens that strong and durable stone is condemned on account of careless methods of handling and laying.

An estimate of the strength and durability of a stone from its condition in a building should only be made after one has considered, (1) the age of the building; (2) its size; (3) the climatic or atmospheric conditions; (4) its position; (5) the grade of stone used, and (6) the manner in which the stone was quarried, handled, dressed, and laid.

The age of a building is especially important, it being worse than folly to pass judgment on the stone in a building, unless this is known. A stone may not exhibit any material deterioration during the first twenty-five years in a wall, although the next ten years may show marked decay. As a rule the actual disintegration of the stone in buildings in the United States is comparatively little. Many that are fifty or more years old do not exhibit the first signs of decay. The actual disintegration is frequently so little that the observer must content himself with searching for the beginnings of decay.

The height of a building usually increases the weight of the superstructure and hastens the rate of decay. The atmospheric or climatic conditions, temperate, torrid, frigid, humid, or arid, will affect the permanence of a rock. A stone which would remain unchanged for centuries in an arid region might crumble and decay in a few years in a moist, temperate climate.

The position of a building, in the business or residence part of a city, protected or exposed to the storms and prevailing winds, will affect more or less the life of the stone.

The grade of stone that has been used in the construction of the building under inspection should be known. Nearly every quarry contains more than one grade of stone. However, it is not an uncommon occurrence for the stone from an entire district to be condemned because second or third grade stone has not proved as satisfactory as number one stone from another district. The poorer grades of stone are sometimes used in the fronts of buildings or even carved for the finer parts of the architectural work.

After the stone once becomes a part of a building people do not stop to distinguish different grades, but charge all weaknesses or imperfections against the quarry as a whole. Sometimes an entire area including several quarries suffers in consequence.

It is also important to know the manner in which the stone is quarried, handled, dressed, and laid. Much stone is still being laid on edge, especially in veneer work. Where the bedding planes are prominent and the stone is only of moderate strength, this practice is dangerous. An observer should ascertain if possible whether the flaking and scaling is due to improper methods of laying or to inherent weaknesses in the stone.

Stone used for ornamental and monumental purposes will show deterioration in proportion to its age, position, etc., the same as stone in the walls of buildings. For these reasons, the same care should be exercised in passing judgment on its durability.

The oldest monuments are built out of marble, it being only within a comparatively few years that granite has come into very general use. Nevertheless, some of the important granite monuments, in spite of the comparatively recent data of their erection, are gradually losing their polish and even now have finely pitted surfaces. Monuments that are exposed for years to dust laden winds frequently have their polished surfaces dulled and the lettering obscured. The sides exposed to the direct rays of the sun often deteriorate most rapidly owing to the diurnal expansion and contraction caused by heating and cooling.

The degree of polish which a stone will take and the contrast of the hammered and polished surfaces can be best estimated from the finished work. One should be mindful, however, at all times, in making comparisons, not to allow the elaborateness or excellence of the workmanship to influence the judgment. Dealers sometimes oil the polished surfaces of the monuments, which gives a brilliancy and luster not inherent in the stone itself. For this reason a monument should only be examined after it has been erected for six months or a year.

In the case of stone used for highways and sidewalks much can be learned of its strength and durability by inspecting previously constructed walks and roadways. In these cases, however, a just comparison can only be made when the manner in which the highway or walk has been constructed, the amount of traffic to which it has been subject, the character of the subsoil, the climate conditions, and the data of construction are known. The rapidity and manner in which a stone pavement wears are the important factors to be determined. An examination of pavements built out of the stone will indicate whether it wears unevenly, is slippery, or is easily abraded.

LABORATORY TESTS

One who is fully acquainted with the mineralogical and chemical composition, the physical characteristics of a stone, and the climatic and other conditions to which it will be subject when in use, can predict with a remarkable degree of accuracy, without inspecting the quarry or examining buildings of long standing, the results of exposure to the atmosphere. It is not always possible to have a laboratory examination made, and frequently it is unsought for by quarrymen, who often prefer to rely upon their own statements to sell their stone.

The important laboratory tests are included under three general classes, viz., (1) chemical; (2) microscopical; and (3) physical.

CHEMICAL

The chemical analysis is the only exact method of determining the composition of a rock in terms of the elements that compose it. It is also the best method of determining the relative proportions of the mineral constituents. The presence of deleterious constituents, such as ferrous iron, bitumen, etc., and the proportion that they bear to the total mass of the rock may also be determined in this way.

MICROSCOPICAL

Much may be learned of the mineralogical composition and physical characteristics of most rocks by a careful examination of the hand specimen, especially with the aid of a magnifying glass. Many rocks, however, are so fine grained that the mineralogical composition and texture can only be accurately determined by an examination of thin sections under a compound microscope.

It is thought that the microscopical examination is of much greater practical importance and less expensive than the chemical analysis. By use of the microscope and thin sections both the mineralogical composition and texture of a rock can be determined with a high degree of accuracy. The relative abundance of the different minerals and even the chemical composition can be approximately estimated. Minerals that are easily decomposed and liable to cause discoloration can be identified, and the presence of cracks, strains, and gas bubbles can be detected. A single caution should be observed in this connection. Cracks and strains are thought to be frequently due to stresses resulting from cutting and grinding the thin section, on account of which care should be exercised in drawing conclusions therefrom. The size and abundance of the pore spaces can be estimated from the texture, closeness, and manner of contact of the grains. All the characteristics of a rock which contribute to its strength, hardness, elasticity, capacity to resist alternating and extreme temperatures, and immunity from the

effects of carbonated or acidulated waters, can be determined by the microscopic examination of thin sections.

It is thought that the use of the microscope, with an intelligent interpretation of the facts revealed thereby, might eventually render unnecessary the performance of the physical tests and the determination of the chemical composition. However, at the present time, this method is only available to the scientist who can interpret the facts thus observed. The accuracy of his conclusions will depend upon his judgment and experience as a petrographer. With the public it may never supplant the physical tests, because it lacks the quantitative element.

PHYSICAL TESTS

The purpose of the physical tests is to determine by artificial methods the strength of a stone and its capacity to resist the destructive agents encountered in actual use. As stated on a previous page, the signs of decay in buildings, on account of the improper methods of quarrying, handling, dressing, and laying are not always evidence of inherent weakness in the stone. For this reason the physical tests, performed in the laboratory, often provide a more reliable basis on which to estimate strength and durability.

It is a comparatively simple matter to determine the strength and elasticity of a stone, both of which can be measured directly by machinery. It is a more difficult problem, however, to express quantitatively the durability, on account of the impossibility of measuring in a few weeks or months in the laboratory any deterioration that might take place under ordinary climatic conditions. Further than this the conditions in nature change from day to day, both in intensity and kind, and as a rule, there are several instead of one agent of destruction operating at the same time. In order to measure the effect of these agents in the laboratory it is necessary to consider them separately, and on such a grossly exaggerated scale that there will be accomplished in a brief period, what in nature would require many years.

Estimates of the strength and durability of a stone from physical tests are usually based upon the following determinations:

1. *Strength,*
   a. Compressive,
   b. Transverse.
2. *Elasticity, modulus of.*
3. *Hardness—coefficient of wear.*
4. *Specific gravity.*
5. *Porosity.*
6. *Weight per cubic foot.*
7. *Effect of Temperature changes,*
   a. Freezing and thawing of included water,
   b. Effect of extreme heat.
8. *Effect of gases,*
   a. Carbonic acid,
   b. Sulphurous acid.

Attempts have been made to classify these tests under "strength tests" and "durability tests," but the classifications thus made are not logical because some of the tests have a double significance.

STRENGTH

A knowledge of the strength of a stone implies a familiarity with its capacity to withstand both compressive and tensile stresses. For this reason both the crushing strength and modulus of rupture should be determined.

Crushing strength.—Up to within a few years the compressive strength test, by means of which the crushing or ultimate strength is determined, has been used for estimating both the durability and strength of a stone. However, a stone with a low crushing strength may be more durable than one in which the crushing strength is high. For this reason the crushing strength, alone, is insufficient for estimating the durability of a stone. In the absence of other tests the importance of the crushing strength has been frequently overestimated.

At the present time, however, it is argued by some that it is folly to determine the crushing strength, except in cases where the strength of the stone is very doubtful. Nevertheless, I do not believe that it is wise to encourage the abandonment of the crushing strength test.

Architects using stone with which they are not familiar, are glad to avail themselves of all crushing strength data. In fact, the only intelligible method of expressing the strength of a stone to one not thoroughly familiar with the interpretation of the mineralogical composition and texture, is in pounds per square inch.

Other than this the crushing strength determinations have an important scientific bearing upon problems in dynamic geology, and for this reason if no other the test should be continued.

It is not uncommon for a stone to be so situated in a building that it must sustain a heavy load. In very large buildings single columns and blocks are often required to carry huge masses of superstructure. Bridge trusses are often supported on blocks of stone which sustain the combined weight of the superstructure. Before using a stone for any of these purposes it is well to know with a fair degree of accuracy its crushing strength.

The pressure exerted on the stone in the lower courses of a building of ordinary dimensions is not very great. It has been computed that the stone at the base of Washington monument sustains a maximum pressure of 22.658 tons per square foot, or 314.6 pounds per square inch. Most architects require a stone to withstand twenty times the pressure to which it will be subjected in the wall. This factor of safety, however, would only require a crushing strength of 6292 pounds per square inch for stone at the base of the Washington monument. The pressure at the base of the tallest buildings yet constructed in this country can scarcely exceed one half that at the base of this monument, or 157.3 pounds per square inch. With a factor of safety of twenty the stone used in such positions must have a crushing strength of 3146 pounds per square inch. There are very few

building stones in the country that do not have a higher crushing strength. It may happen, however, that owing to an unequal distribution of the load certain stones in the wall or columns, will be called upon to sustain twenty, or even fifty times the natural load, in which case the crushing strength should be much greater. All things considered, however, a crushing strength of 5000 pounds per square inch is considered sufficient for all ordinary building constructions.

The crushing strength of a stone can be obtained quickly and accurately in any laboratory which is provided with appliances for cutting and dressing stone cubes and a testing machine, for determining the compressive strength. The cubes to be tested should measure uniformly $2 \times 2 \times 2$ inches, this being generally conceded to be the standard size. Smaller or larger cubes may be used, but some authors, following the early experiments of General Gilmore, still maintain that the crushing strength per unit of area varies with the size of the cube tested. Believing this, General Gilmore constructed an empirical formula for the purpose of reducing all tests to pounds per square inch on two-inch cubes. However, it has been shown to the satisfaction of most persons, that this formula is neither theoretically nor practically true. It is now believed quite generally that the crushing strength per square inch is the same whether the cubes tested be large or small; cubical or prismatic in shape. Until this question is settled to the satisfaction of all it is best that all tests be made upon two-inch cubes.

The cubes should be very carefully sawed from stone which has not been injured by rough handling or hammer dressing. The faces should be rubbed smooth, and the opposite sides should be made parallel. Before the cubes are placed in the testing machine they should be thoroughly dried and the average area of the bearing faces determined. Thin strips of blotting paper, wood, or lead, are often placed between the steel plates of the machine and the bearing faces of the stone cubes, to assist in distributing the load. It is claimed by some, however, that this has a tendency to lower the crushing strength. The

author believes, that for the sake of uniformity, at least, it would be best to apply the bearing faces directly to the steel plates of the machine, a spherical compression block being used in making the test. Record should be kept of the direction in which the pressure is applied with respect to bedding.

The load at which the cubes are first cracked, the ultimate strength, the perfection of the resulting pyramids, and the explosive manner in which the cubes break should be carefully noted. The crushing strength per square inch is computed by dividing the ultimate strength by the average area of the bearing surfaces in square inches.

Transverse strength.—The transverse strength is measured in terms of the modulus of rupture. This is the force required to break a bar of any material one inch square, when resting on supports one inch apart, the load being applied in the middle. The determination of the modulus of rupture is of far greater importance in masonry construction than would be supposed from the very meager data available. The broken lintels, caps, and sills which are so conspicuous in many of the larger buildings in this country, testify to the need of a more general appreciation of the value of this test. Many building stones that are perfectly suited to withstand the compressive stresses in the body of the wall, have such a low modulus of rupture as to be unfit for use in a position where a high transverse strength is required.

The necessary thickness of a lintel, cap, or sill depends mainly upon the transverse strength of the stone. In order to avoid possible danger from weak stone or unequal stresses, the doors and windows of the heavier buildings are often arched.

For the purpose of obtaining the modulus of rupture, pieces should be prepared by sawing, and should have a cross section of one square inch and a length of from six to eight inches. The sides should be smooth and the opposite faces parallel. The pieces thus prepared should be placed in a testing machine, in which both ends are supported and the pressure applied in the middle. The weight required to break the sample and the

position of the rupture should be carefully recorded. The modulus of rupture is then computed from the following formula:

$$W = \frac{2bd}{3l} R, \text{ from which}$$

$$R = \frac{3l}{2bd} W.$$

W = concentrated load at center in pounds.
b = breadth in inches.
d = depth in inches.
l = length.
R = modulus of rupture in lbs. per sq. in.

Modulus of elasticity.—The modulus of elasticity is synonymous with coefficient of elasticity, and is sometimes defined as the weight that would be required to stretch a rod one square inch in section to double its length. The result is generally expressed in pounds per square inch. It is "valuable in determining the effect of combining masonry and metal, of joining different kinds of masonry, or of joining new masonry to old; in calculating the effect of loading a masonry arch; in proportioning abutments and piers of railroad bridges subject to shock," etc. Baker.)

One method of measuring the modulus of elasticity is by recording the amount of compression which a two-inch cube of stone undergoes for each increment of 500 to 1000 pounds up to the limit of elasticity. From the data thus obtained the modulus of elasticity is computed by use of an empirical formula.

The value of such determinations from a commercial standpoint are somewhat doubtful, owing to the fact they are seldom referred to by architects. The sparcity of the determinations in this country is undoubtedly one reason for their uselessness.

Hardness.—The hardness of a stone may be determined quantitatively by the use of an abrading machine, and the results expressed as the coefficient of wear. The abrasion test is used mainly for determining the wearing qualities of crushed rock for

macadam but it is thought that such tests will prove valuable and important for determining the suitability of stone for steps, sidewalks, and flooring.

The abrading machine that is considered best suited for determining the coefficient of wear is that used by the Wisconsin Geological Survey, and patterned after the machine used by the Massachusetts Highway Commission.[1]

Specific gravity.—The determinations of the specific gravity of building stones that have come under my observation have been based upon two very different conceptions. According to one of these conceptions the specific gravity depends entirely upon the mineralogical composition, and is independent of the porosity of the stone. According to the other conception the pores are considered a part of the stone and the specific gravity is computed for the exterior volume. These two methods give different results for the same stone, and have been designated by Regis Chauvenet as "Specific Gravity Proper" and "Apparent Specific Gravity." Where the porosity of a stone is less than 1 per cent. the two specific gravities are almost the same. But where the porosity is 10 or 25 per cent., they are very different.

In most discussions of building stone tests the principle laid down by Professor J. C. Smock[2] that, the specific gravity of the *particles or mineral species* composing the rock mass, determines that of the stone has been followed.

The practical engineer, however, objects to this method, because he cannot compute the weight of the stone per cubic foot directly by multiplying by 62.5, the weight of an equal volume of water. Several contemporary writers on building stones, however, have unfortunately made the mistake of determining the "specific gravity proper" and then computing the weight per cubic foot by multiplying this directly by 62.5. For

[1] For description of this machine see the Report of the Massachusetts Highway Commission for 1899, pp. 59, 60.

[2] Bulletin of New York State Museum, Vol. II, No. 10, p. 374, PROFESSOR J. C. SMOCK.

example one author gives the following as the results of his experiments on three different stones.[1]

Number	Specific gravity	Weight in lbs. per cubic foot	Per cent. of water absorbed
C 2314	2.6236	163.50	18.07
C 2183	2.6166	163.07	3.62
C 2316	2.5380	158.17	8.71

It will be observed as a result of these experiments that the stone which absorbed 18.07 per cent. of water weighed more than the one that absorbed only 3.62 per cent., although the difference in specific gravity is only .007.

Another author says: "If we find that a stone has a specific gravity of 2.65 . . . . we get its weight by simply multiplying 62.5 by 2.65 which gives us 165.62 . . . ."[2] In this statement reference is made to the "specific gravity proper" and not the "apparent specific gravity." Results obtained in this way would obviously be incorrect. Similar inaccuracies in the determination of the specific gravity and weight per cubic foot, occur in other published reports, but those above quoted suffice as illustrations.

I believe that the specific gravity should be determined on the principle laid down by Professor J. C. Smock[3] and that the "apparent" specific gravity should only be used in computing the weight of the stone per cubic foot. There is no inconsistency in this, in so much as the commercial weight considers only the external volume and does not consider the stone as a geometric solid. At least there should be a recognized uniform method of computing the specific gravity of stone.

The specific gravity proper of a rock can only be obtained by weighing the samples in air, at a definite temperature, after all interstitial water has been expelled; then weighing them,

[1] Bulletin of New York State Museum, Vol. II, No. 10, Table, p. 358, by FRANCIS A. WILBER.

[2] The Building and Decorative Stones of Maryland. Maryland Geological Survey, Vol. II, p. 119, GEO. P. MERRILL.

[3] *Ibid.*

completely saturated with water, in water; and finally dividing the weight in air by the difference. These ideal conditions of absolute freedom from interstitial water in the one case, and complete saturation in the other, are difficult to obtain. Nevertheless, if accurate methods are employed and care is exercised in manipulation it is thought that a high degree of accuracy can be attained.

As previously stated, it is advisable to perform all tests on two-inch cubes. In obtaining the specific gravity, the samples should be cleaned by carefully washing, and dried for twenty-four hours in a hot air bath at a temperature of 110° C. The samples should then be weighed and the weights recorded in grams to the second decimal place. The samples should then be transferred to a large bottle or other glass receptacle, corked tightly, and sealed. This bottle should then be transferred to a water bath having a temperature of 100° C. Three glass tubes, one leading to an air pump, another to a manometer, and a third to a basin of boiling water are passed into the bottle through holes in the cork. By means of the air pump, the air in the bottle should be exhausted until the pressure, as indicated by the manometer attachment, is lowered to at least one twelfth of an atmosphere. The pressure should be maintained at this point while distilled water at a temperature of 100° C is drawn into the bottle through the third tube. This tube which conveys the water should be partly rubber and should extend to the bottom of the bottle. A stop cock is used to regulate it. By starting the air pump and operating the stop cock at the same time it is possible to keep the pressure nearly constant and at the same time draw any desired amount of water into the bottle. By this process, the air in the pores is gradually replaced by the water which fills the vessel from below. After the cubes are completely covered with water, they should be allowed to remain in the bottle twenty-four hours maintaining a pressure of one twelfth of an atmosphere.

The saturated samples should then be quickly transferred to a basin of distilled water and removed to the weighing room.

After removing the samples from the basin, the water adhering to the surface should be deftly removed by the use of bibulous paper, the samples transferred to the scale pan, and quickly weighed. Through the transference of the samples from the basin to the scale pan there are two sources of error, one is through the use of bibulous paper, and the other through evaporation. No plan has yet been devised to avoid these sources of error, wherefore the skill and judgment of the operator must be depended upon.

After these weights are recorded the samples should be suspended by a silk thread in distilled water and again weighed. After this weight is recorded the samples should be transferred to a hot air bath and dried at a temperature of 110° C. until the interstitial water has been entirely expelled. The samples are again weighed and the results recorded. From the weights thus obtained the specific gravity is determined by dividing the average of the two dry weights by the difference between the average dry weight and the weight of the cube suspended in water.

The apparent specific gravity can be readily obtained by subtracting the weight of the sample suspended in water from the weight of the sample saturated with water and dividing the average dry weight by this difference.

Porosity and ratio of absorption.—These terms have been used interchangeably as applying to the percentage of the weight of the absorbed water to the average weight of the dry sample. This ratio, however, is not the percentage of actual pore space, but simply the relation between the weight of the rock and the weight of the water absorbed. The term porosity should only be applied to the percentage of actual pore space in the rock while the ratio of absorption should be restricted to the percentage of the weight of the absorbed water to the average weight of the dry sample. The former gives the volume relation and the latter the weight relation. To my knowledge no American writer has computed the actual pore space or porosity of building stones. However, I believe that this determination is more important than the ratio of absorption.

The method of obtaining the porosity which is ordinarily employed is as follows: The sample to be tested is heated at a temperature of 100° C. to drive off the moisture. After cooling, the sample is weighed, and then slowly immersed in distilled water. After bubbles cease to be given off, the sample is removed from the water and the surface quickly dried with bibulous paper, after which the specimen is again weighed. The difference in weight gives the increase due to the absorption of water. This difference divided by the weight of the dry stone is taken as the ratio of absorption or porosity.

Several errors are apparent in this method. The interstitial water is not easily expelled at a temperature of 100° C. To expel the moisture in a moderate length of time, the stone should be dried at a temperature of 110° C. Further, the samples cannot be completely saturated "by immersing in distilled water until bubbles cease to be given off." Finally the method of computation gives the ratio of absorption and not the percentage of actual pore space or porosity.

The porosity of a stone should be obtained in the following manner, using the determinations made in performing the specific gravity tests. The average weight of the dry sample should be subtracted from the weight of the saturated sample, to obtain the weight of the water absorbed. This, multiplied by the specific gravity of the stone, will give the weight of a quantity of stone equal in volume to the pore space and of the same specific gravity as the stone tested. This weight divided by the weight of the dry stone will be the porosity or actual percentage of pore space.

The ratio of absorption can be obtained by dividing the weight of the absorbed water by the weight of the dry stone.

In another part of this paper I have shown that neither the porosity or ratio of absorption, alone, indicates the value of a stone for building purposes. It was pointed out that the size of the pores is by far the more important consideration. This can be estimated roughly, when the size and shape of the grains and percentage of pore space are known. If only the ratio of

absorption is available the calculations of the size of the pores are liable to be less accurate.

For scientific purposes, other than determining the quality of a stone for building, the porosity, and not the ratio of absorption is the factor sought after. The porosity test will result in a higher percentage than the ratio of absorption, and may therefore meet with disfavor among quarrymen. However, when it becomes known that the value of a stone cannot be estimated from its porosity except when the size of the pore spaces is known, objections will cease. In all cases it is thought that the porosity should be determined in preference to the ratio of absorption.

Weight per cubic foot of stone.—The weight of stone when it is first quarried, depends upon its specific gravity, the amount of pore space, and the water content. For a given stone, the only fluctuating element is the water content. In the more porous rocks this will vary at different seasons of the year and will depend upon the thoroughness with which the rock has been seasoned. Any determination of the weight per cubic foot of a stone which includes an indefinite quantity of interstitial water is unscientific and unsatisfactory. Determinations thus made depend upon a number of conditions, changes in any one of which will give a different result. The only constant weight is that of the dry stone.

The commercial weight of a stone may be obtained in two ways. First, by weighing directly a known volume of the stone which has been thoroughly dried at a temperature of 110° C.; second, by computation from the data obtained in determining the porosity. By the second method, the weight of a cubic foot of stone can be obtained by multiplying the weight of a cubic foot of water by the specific gravity proper of the stone and subtracting therefrom the weight of a mass of stone, equal in volume to the pore space of the given rock and of the same specific gravity.

A simpler method would be to compute the apparent specific gravity as directed above and multiply by 62.5, which should give the same result.

Effect of temperature changes.— The durability of a stone depends very largely upon its capacity to withstand temperature changes. Such changes may affect the mineral constituents of rock through expansion and contraction, or they may cause the interstitial water to freeze and thaw, on account of which the strength of the stone may be materially lessened.

Very few tests have thus far been made to determine the effect on building stone, of the alternate freezing and thawing of interstitial water. The importance of such experiments has never been questioned, but the difficulty of manipulation and the many conditions which need consideration before conclusions can be drawn from the quantitative results, have had the effect of almost excluding these tests from the experiments on building stone.

The effect of alternate freezing and thawing may manifest itself in three ways: first, cracks may form; second, small particles or grains may be thrown off from the surface occasioning a loss in weight; third, the strength of the sample may be lessened. The first result is very seldom observed in testing samples in the laboratory, owing to the careful selection of the pieces tested. The other two, however, usually occur and can be measured quantitatively.

Two methods, known as the natural and the artificial, have been employed to determine the effect of alternate freezing and thawing of the interstitial water. The natural method is to soak the samples with water and alternately freeze and thaw them, a few or many times, at the convenience of the operator. The artificial method is to saturate the stone in a boiling solution of soluble salt, such as sodium sulphate, and then allow it to dry. As the water evaporates the salt crystallizes and expands, producing stresses similar to those which result from freezing water. It appears to me that the only instance in which it is excusable to use this method is when there is no opportunity to freeze the samples under conditions which more nearly accord with those which occur in nature.

For the purpose of testing stone according to the natural method, the operator should use two-inch cubes as in the

previous experiments. If the tests are made during the winter months when the temperature is below the freezing point, the samples can be saturated with water, cooled to nearly the freezing point, and then placed out of doors. If freezing temperatures do not prevail in the climate where the experiments are being performed, access may be had to a cold storage building where the necessary temperature may be obtained. Freezing mixtures may also be used to produce the desired temperature.

The samples to be tested should first be thoroughly cleaned and dried in a hot air bath at a temperature of 110° C. and weighed. After the samples are thoroughly saturated with distilled water, after the manner outlined in the specific gravity test, they should be cooled almost to the freezing point, taken from the water and removed to the place of freezing and allowed to remain for twenty-four hours. The samples should be thawed, saturated, and frozen alternately each day for a period of thirty or forty days, after which they should be placed in a hot air bath and dried at a temperature of 110° C. They should then be removed to the weighing room and weighed. This final weight subtracted from the first gives the loss in weight. The samples should be examined to discover any cracks that may have formed as a result of the freezing.

Finally the frozen cubes should be crushed in a testing machine to determine their compressive strength. The results thus obtained should be compared with the strength tests made on unfrozen cubes of the same stone.

The loss in weight during a period of thirty-five days has been found to be due mainly to the removal from the surface of small particles which were previously loosened, in the process of cutting the sample. Many of the grains at the surface of sandstone samples which have been sawed or hammer-dressed are partly loosened. Such grains fall away from the mass of the stone very easily. The pressure which is supplied by the freezing water, which fills the cracks and pores near the surface, is abundantly able to accomplish this.

Naturally, sedimentary rocks, such as sandstone, have more loose grains at the surface than the igneous rocks or finely crystalline limestone. However, in any case, alternate freezing and thawing for a period of thirty-five days will scarcely result in anything further than the removal of the loose particles from the surface. If the process is continued for another thirty-five days it is probable that in the case of sandstone the loss during this period will be far less than that of the first period. Even though the loss should be as great, the results could not be justly compared, except between the same kinds of stone.

To my knowledge, the loss in crushing strength due to freezing has not received the least consideration by any previous writer on building stones. As inferred above, I believe that the tests heretofore made to determine the loss in weight are of comparative little value in estimating the effect of freezing and thawing on the durability of a stone. The determination of the loss in crushing strength is obviously more important. It is evident that if a stone is saturated with water and frozen while a portion of the pores are still filled with water and the process is repeated a score or more of times, the adhesion of the particles will be weakened. It is not reasonable to suppose that the strains produced can be measured by the immediate loss in weight. It is plausible to suppose that the deterioration can be better measured by the loss in strength.

Experiments performed in the preparation of the report on the "Building Stones of Wisconsin" confirm my impression regarding the value of the crushing strength test applied in this manner. I feel quite confident that this test is more important than the determination of the loss in weight, and should, I believe, eventually take precedence in the testing of building stones.

Extreme heat.—Very few tests have been performed to ascertain the effect of heat or cold when applied directly to stone, yet it is known from observation that rapid and extreme changes in temperature weaken a rock and often cause disintegration. In large cities, the capacity to withstand extreme heat is one of

the essential qualities of a good building stone. In the conflagrations which have occurred in many cities, brick, stone, and wooden structures have suffered alike. Granite and brick walls have crumbled into shapeless masses, while iron beams and girders have been melted and twisted into all conceivable shapes.

A comparatively low temperature destroys some materials, while others are barely affected at a temperature above the melting point of copper. Most building materials, however, are destroyed when subjected to a very high heat.

It is known that rocks are poor conductors of heat, and for this reason the outer shell of a block may be very highly heated while the interior is comparatively cold. If a block is quickly cooled after heating, contraction of the outer shell takes place, and the differential stresses occasioned thereby rupture the rock.

The destruction caused by a conflagration is largely increased by streams of water which are thrown onto the burning buildings in an attempt to extinguish the flames. If the fire occurs in winter the effect is still further intensified by the freezing of the water.

Few experiments have thus far been performed to determine the temperature which the different kinds of stone will stand without injury. It has, however, been demonstrated that stone will withstand a much higher temperature when heated and cooled slowly than when heated and cooled rapidly.

The easiest method to test the capacity of a stone to withstand heat is to place two-inch cubes in a muffle furnace and gradually heat them from a low to a high temperature. By using a standard pyrometer the temperature can be gauged and the visible effect of any increase in heat can be noted. Samples should be tested not only to ascertain the effect of gradual heating and cooling, but they should also be removed from the furnace and suddenly cooled by plunging into cold water.

Limestone and dolomite are injured mainly through calcination, although when suddenly cooled they flake at the corners. Coarse grained granite is often shattered throughout its mass. Medium grained granite flakes at the corners, while the compact,

fine grained varieties are often traversed by sharply defined cracks. In contrast with the limestone and granite, sandstone has all outward appearance of being very little injured by extreme heat. However, it is often so soft after being subjected to extreme heat that one can crumble it between the fingers. The extent to which a coarse grained sandstone has been injured by extreme heat cannot be determined until the strength of the stone has been actually tested. All the stone that has been heated to a high temperature emits the characteristic ring, and scratch of brick. The cause for this may be found in the loss of the water of composition by the minerals of the rock.

Experiments seem to indicate that there are few, if any, stones, whether they be granite, limestone, or sandstone, that will effectually withstand a temperature of 1500° F. A rock with a uniform texture and a simple mineralogical composition apparently suffers the least injury when subjected to high temperatures.

It would be interesting to know the loss of strength occasioned by each increase in temperature of 100 or 200° for the different kinds of building stones. This can only be determined by a careful series of experiments, and it is hoped that in the future some one will undertake this task.

The effect of sulphurous acid gas.—Limestone, dolomite, and marble are the only kinds of stone which are to any extent injured by sulphurous acid gas. To determine the effect of this gas upon dolomite or limestone, two-inch cubes are dried at a temperature of 110° C. and carefully weighed. They are then placed in a wide mouthed bottle, in the bottom of which is placed a beaker of water to keep the air moist. The bottle is sealed and each day sufficient sulphur dioxide is transferred into the bottle to keep the atmosphere saturated. The samples should be allowed to remain forty-four days in this atmosphere saturated with sulphur dioxide. After being removed from the bottle the samples should be washed and thoroughly dried at a temperature of 110° C. They should finally be weighed and the loss in weight determined. The percentage of loss in weight is taken as the result. The loss in this case is due mainly to the

magnesium and calcium salts which collect at the surface and are dissolved by the water when the samples are washed.

Effect of carbonic acid gas.—The effect of carbonic acid gas on limestone is determined in the same manner as that of sulphurous acid gas. The samples are dried at a temperature of 110° C. and weighed. They are then placed in a wide mouthed bottle which is filled with carbonic acid gas. A beaker of water is placed in the bottle to keep the atmosphere moist. After being treated for forty-four days the samples are removed, washed, and weighed. The percentage of loss in weight is taken as the result.

Sulphur dioxide and carbon dioxide probably do not at any time exist alone in the atmosphere. The effect of these gases acting together or in conjunction with the many less abundant gases of the atmosphere may produce very different results than when acting separately.

E. R. BUCKLEY.

GEOLOGICAL AND NATURAL HISTORY SURVEY.
Madison, WIS.

EDITORIAL

An unsigned article in *Science* (June 22) entitled "Sigma Xi at the American Association for the Advancement of Science," calls attention approvingly to a movement to associate meetings of this Greek-letter society with those of the Association. The rapid rise of the Sigma Xi in American universities is cited, and it is affirmed that "as an honor society it promises to take a leading part in our universities in which science holds a prominent place." It is urged that "it has become a representative honor society for the ablest students of science in the institutions where it is established." Respecting its intent, the following authoritative quotation is made: "In establishing a new chapter . . . . in each case we should make sure that we entrust the power of distributing the honor of membership only to such persons and institutions as are capable of giving the education and training necessary to the carrying on of scientific investigation."

It is scarcely necessary to make these quotations to show that the fundamental feature of the society is the promotion of a class distinction based on academic preparation. However laudable this may be, in itself considered, it would seem to be inharmonious with the fundamental purpose of the Association, which is the development and dissemination of science among all people without regard to race, age, sex, or previous condition of intellectual servitude. From professional relations the writer should not be inappreciative of the value of university training and of academic achievement. Nevertheless, it seems to him that the purposes of the Association are unqualifiedly democratic and that the spirit of science is equally so, and that therefore the only distinctions which the Association should foster or sanction, if it fosters or sanctions distinctions at all, are those which are based solely upon scientific productiveness. And this productiveness should be honored quite irrespective of its connection

with the fortunate conditions of academic appointments and opportunities, or with the adverse or even hostile conditions under which much good science has been developed. The movement therefore to connect the meetings of the Sigma Xi with those of the Association seems incongruous.

As set forth in another article in the same number of *Science*, some fifteen special scientific societies have already become correlated with the Association and have much increased the complexity of the proceedings. This movement seems to be an inevitable consequence of the differentiation of scientific work, and is scarcely less than necessary to the continued success of the Association, but it has already brought some inevitable conflict of interests and not a little congestion of programs and appointments. Between these and the increased number of social functions, it has already come to pass that there is little time left for that personal conference and that informal sociability whose basis is "shop talk," which formed so large a factor in the attractiveness of the earlier meetings of the Association. If now in addition to these laudable complications, the attention of a considerable number of the members of the Association is to be diverted in the interest of an academic honor society and a precedent established for the meeting of other societies whose basis is not strictly congenial to that of the Association, it is not clear where the limit of congestion will be found.

Between the lines of the article referred to, the imagination is tempted to read a hint of a desire for that rank and dominance in the Association which the members of Sigma Xi attained in university circles, and it is not unnatural to anticipate that the fraternity might unconsciously play a part in Association politics not unlike that for which Greek-letter societies are famous throughout the university world. To those who pride themselves upon rank and band themselves together because of rank it is not unnatural that official expressions of rank should be sought through the unconscious influence of fraternization.

It is not altogether foreign to the subject of this discussion to note the increasing encroachments of formal social functions

upon the meetings of the Association and not less perhaps upon the meetings of the Geological Society of America. Without doubt a certain measure of formal contact with general society is helpful to the ends sought by the Association. At the same time it must be recognized that formal social functions are largely the province of the leisure class and that from the very nature of the case they must remain so, for leisure and the means of leisure are prerequisites to their effective cultivation. Equally from the nature of the case, the devotees of science do not usually belong to the leisure class because real success in science involves strenuous endeavor and an almost unlimited devotion of time. The diversion of time to social functions during the meetings of the Association should, therefore, be zealously watched and restrained within limits which are compatible with the efficient conduct of the primary purposes of the Association. Particularly is this true of the Geological Society which has no organic relation to general society. The movement in the direction of social formality has already crowded hard upon the point where the first requisite preparation for a meeting of the Association or of the Geological Society is the packing of a dress suit, and the second is the preparation of an after-dinner speech, preparations that are none too congenial to the great mass of hard workers in science.

T. C. C.

Reviews

The Illinois Glacial Lobe. By FRANK LEVERETT, Monograph XXXVIII, U. S. Geological Survey, pp. 817. Plates XXIV, 9 figures. Washington, 1899.

This is one of a series of monographs in course of preparation by the Glacial Division of the United States Geological Survey, whose purpose is to set forth the salient features of the glacial formations preparatory to more detailed mapping by quadrangles, which the survey is undertaking, and by counties and other appropriate divisions, which many of the states are prosecuting. In a sense it may be said to be the first monograph of the systematic series. Two other monographs have been published, namely, that on Lake Agassiz, by Mr. Warren Upham, and that on the Glacial Gravels of Maine, by Professor George H. Stone, but these are special treatises on phenomena of exceptional interest and only indirectly form a part of the systematic series intended to cover the glacial area. The plan of the Survey departs somewhat widely from that prevalent in Europe where glacial work proceeds largely by minute studies of small areas without previous determination of the great features and broader classifications which can only be worked out by connected studies over large areas. The method of the United States Geological Survey has been to determine first these grand features and leading classifications and then descend in natural order to local details and more refined studies. Local mapping proceeds at great disadvantage without such preliminary determinations, for such is the nature of the glacial formations that these larger expressions of the phenomena of the period are very imperfectly expressed within any restricted area, and are quite beyond satisfactory interpretation unless the studies are extended beyond them.

The general reconnaissance work of the survey was essentially completed some years ago by the geologist in charge and the work of preparation of the monographs, as the second step of the plan, is now well under way. Besides the monograph under consideration, the manuscript of an additional one has been submitted and work upon a third is in progress.

The products of the Illinois glacial lobe constitute a natural monographic theme, for the differentiation of the border tract of the ice by the topographic influences of the trough of Lake Michigan gave the lobe a quite distinct individuality. In the monograph, however, for convenience the field is rather arbitrarily limited on the north where the products of the Illinois lobe become complicated on the east side with those of the Huron-Erie and the Saginaw lobes and on the west side with those of the Green Bay lobe. This limitation, however, does not seriously affect the unity of the theme. This lobe was given precedence because its field embraces the most southerly reach of the great ice mantle and because its products are unusually well deployed.

The author's abstract of the monograph which follows, sets forth its contents better than could be done by another.

Chapter I. Introduction.— The Illinois glacial lobe formed the southwestern part of the great ice field that extended from the high lands east and south of Hudson Bay southwestward over the basins of the Great Lakes and the north-central states as far as the Mississippi valley. It overlapped a previously glaciated region on the southwest, whose drift was derived from an ice field that moved southward from the central portion of the Dominion of Canada as far as the vicinity of the Missouri River. This southwestern part of the eastern ice field, being mainly within the limits of the State of Illinois, has received the name Illinois Glacial Lobe.

The results of earlier studies by Chamberlin, Salisbury, and others are noted, and the plan of investigation is set forth. A brief explanation of the method of numbering townships is presented.

Chapter II. Physical features.— The variations in altitude are set forth in a topographic map and also in tables, and the marked increase in altitude of certain parts of the region because of drift accumulations is considered. The conspicuous reliefs of the rock surface are briefly touched upon, and the preglacial valleys receive passing notice. Profiles and maps are extended across the bed of Lake Michigan as well as border districts, and the inequalities of the lake basin are briefly discussed.

Chapter III. Outline of time relations or glacial succession.— A sketch of the major and minor divisions of the drift sheets and of the intervals between them is accompanied by a brief explanation of the basis for the classification adopted.

Chapter IV. The Illinoian drift sheet and its relations.— The Illinoian is the most extensive drift sheet formed by the Illinois glacial lobe and receives its name because of its wide exposure in the State of Illinois. The evidence that the Illinoian drift sheet should be separated from the outlying and underlying drift is briefly set forth. The aspects of the Illinoian drift

sheet are then discussed, its topography as well as its structure being considered. In connection with this drift sheet a very adhesive clay known as "gumbo," which caps it, is described and the questions of its relation to this drift sheet and to the overlying loess are considered. A detailed description of the border of the Illinoian drift sheet is then given, which is followed by a description of the moraines and other drift aggregations back from the border.

Remarkable instances of the transportation of rock ledges are noted. The striæ pertaining to this invasion are discussed in some detail. The effect of this ice invasion and its drift deposits upon the outer-border drainage is touched upon, but the detailed discussion of the influence of the drift upon drainage is deferred to a later chapter. The chapter closes with a discussion of the deposits which underlie the Illinoian drift sheet.

Chapter V. The Yarmouth soil and weathered zone.— A well-defined soil and weathered zone which appear between the Kansan and Illinoian drift sheets in the overlap of the latter upon the former are described, and sections are represented which show clearly the relations to these drift sheets. The amount of erosion effected during the interglacial stage is also considered. The name Yarmouth is taken from a village in southeastern Iowa, where the interglacial features were first recognized by the writer.

Chapter VI. The Sangamon soil and weathered zone.— Another well-defined soil and accompanying weathered zone which appear between the Illinoian drift and the overlying loess are described. The name Sangamon is applied because these features are exceptionally well developed in the Sangamon River basin in Illinois and were there first noted by Worthen in the early reports of the Illinois Geological Survey.

Chapter VII. The Iowan drift sheet and associated deposits.— The name Iowan was applied by Chamberlin to a sheet which is well displayed in eastern Iowa and which had been brought to notice by McGee. The chapter opens with the discussion of a drift sheet of a similar age which was formed by the Illinois lobe, its extent, topographic expression, and structure being considered. The relation of this ice lobe to the Iowa ice lobe, and the relation of each to the great loess deposit of the Mississippi basin are then considered, after which the loess is discussed. The problem of the mode of deposition of the loess forms the closing topic.

Chapter VIII. The Peorian soil and weathered zone (Toronto formation). The name Toronto formation, suggested by Chamberlin, for interglacial deposits exposed in the vicinity of Toronto, Canada, may prove to be applicable to a soil and weathered zone which appear between the Iowan drift sheet or its associated loess and the Shelbyville or earliest Wisconsin drift sheet which overlies the Iowan. Exceptionally good exposures of a soil and weathered zone at this horizon in the vicinity of Peoria, Ill., make it seem

advisable to apply the name Peorian, while the relations of the Toronto formation remain uncertain, Other exposures as well as those near Peoria are discussed. A marked interglacial interval between the Iowan and Wisconsin stages of glaciation may also be inferred by a comparison of the outline of the ice sheet at the Iowan stage of glaciation with that of the outline at the culmination of the Wisconsin stage. It may also be inferred by a change in the attitude of the land, by which better drainage conditions were prevalent in the Wisconsin than in the Iowan stage.

Chapter IX. The early Wisconsin drift sheets. — The Wisconsin drift, named by Chamberlin from the state in which it was first recognized as a distinct drift, is characterized by large morainic ridges and comparatively smooth intervening till plains which have been thrown into two groups, known as the early Wisconsin and late Wisconsin. In the first group the moraines form a rudely concentric series, which are well displayed in the northeastern part of Illinois, but are largely overridden by the moraines and drift sheets of the later group in districts farther east. The outer border of the second, or late, Wisconsin group is so discordant with the moraines of the first group that there seems in this feature alone sufficient reason for separation.

The several morainic systems of the early Wisconsin group are taken up in succession from earlier to later, the distribution, relief, range in altitude, surface contours, thickness and structure of the drift, and the character of the outwash being considered. In connection with each morainic system the associated till plains are discussed, attention being given to the surface features and to the structure and thickness of the drift. In northern Illinois the several morainic systems are merged into a composite belt so complex that it is difficult to trace the individual members.

The several moraines and their associated sheets of till do not appear to be separated by intervals so wide as are found between the Illinoian and Iowan or the Iowan and Wisconsin drift sheets. Indeed, instances of the occurrence of a soil or a weathered zone between Wisconsin sheets are very rare. There may, however, have been considerable oscillation of the ice margin.

Chapter X. The late Wisconsin drift sheets. — The basis for separation from the early Wisconsin is first considered, after which the several morainic systems and their associated till plains are taken up in order as in the discussion of the early Wisconsin drift. An interpretation of the Kankakee sand area is attempted, though several questions connected with it still remain open. The chapter closes with a discussion of the striæ found within the limits both of the early and of the late Wisconsin drift.

Chapter XI. The Chicago outlet and beaches of Lake Chicago. — That a body of water once extended over the low districts bordering the southern end of Lake Michigan and discharged southwestward to the Des Plaines and thence into the Illinois River has been recognized since the early days of

settlement, and several papers discussing the beaches and the outlet have appeared. The latter has long been known as the Chicago outlet, because it led away from the site of that city. The lake has recently been given a name in harmony with that of the outlet (Lake Chicago).

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it affects profoundly nearly all of the larger questions of glacial history.

The distinction between the ages of the several glacial sheets is founded upon careful estimates of the amounts of erosion they have respectively suffered, upon the depths and extent of the weathering process as exhibited alike in the clays and in the pebbles and bowlders, upon the degree of constructive mineralization in the form of segregates and general induration of the deposits, upon the extent of interglacial accumulations of soil, peat and similar deposits, and upon the nature of the life which occupied the region between the glacial stages, together with incidental criteria of more special nature and limited application. When it is considered that the broad sheet of Kansan till, which shows indubitable evidence of having been spread out as an approximately plane sheet, has been so thoroughly eroded over very large areas that only remnants of the original plane remain here and there, it is impossible for the candid mind to resist the conviction that it is very widely separated in age from the later drift-sheets which have been merely ditched by the water courses, leaving scattered over the broad, scarcely modified surfaces, multitudes of shallow basins which a few feet of cutting would completely drain.

While not new, the monograph brings out into sharp definition the lobate character of the ice margin at all of its stages. At the same time it shows that there was a change in the configuration of these lobes at different stages. It is perfectly clear from the general nature of these configurations that they are fundamentally dependent upon the topography of the region they occupy and of that which lies backward along the line of glacial invasion. At the same time there are some anomalies which, while not defiant of topography, do not clearly show their dependence upon it and indicate that other factors than topography were involved in determining the development of the ice lobes. These other agencies are very likely climatic, but they have not yet been deciphered. The most notable of these anomalies are the peculiar forms assumed by the Iowan drift and the shifting in the contours of the lobes between the earlier and later Wisconsin stages.

Closely allied to this variation in configuration is a remarkable variation in the mode of action of the ice at different stages to which the monograph contributes a large mass of data. The earlier drift-sheets

are spread widely over the country without evidences of profound abrasive action upon the pre-existing surface, not that such action was absent, but it was far less vigorous than in the later stages. In harmony with this milder action upon the face of the country invaded, the drift-sheet itself was spread much more uniformly than in later times and pronounced morainic ridges are much more rare, and when present are much feebler and less characteristic. At the same time, the glacial drainage appears to have been much less vigorous and in some instances surprisingly lacking in vigor. These phenomena are among the most suggestive that yet await causal explanation.

By far the most careful and trustworthy estimate of the average thickness of the drift which has heretofore been made in this country is embraced in chapter XIII of this monograph. Not only are the data much more ample and better distributed than those that have heretofore been at command, but they have been analytically classified and discussed by more critical methods. The most difficult element of the problem is the drift embraced in the preglacial valleys, the depth and configuration of which it is difficult to estimate. This has been attempted, however, along two different lines which give essential concordant results, and it is a fair presumption that the total estimate of the mass of the drift of the region investigated is a not distant approximation to the real facts. How far the territory of the Illinois glacial lobe is representative of the average thickness of the drift throughout the glaciated region cannot now be determined, for if the great Canadian tract be embraced, as it should, our knowledge is best defined by emphasizing its limitatations; but the average thickness in Illinois may rudely represent the average thickness for areas similarly situated near the border of the glaciated area, but even this cannot be confidently affirmed.

The work of Mr. Leverett is conspicuous for the judicial attitude of mind which eminently controls it. The emotional factor is held in marked abeyance and the intellectual factor suffers little trammeling from predilections. At the same time the large area covered by critical study testifies to an industry which could not have been greatly enhanced by emotional enthusiasm. The monograph will be best appreciated by those who are most familiar with the ground.—T. C. C.

Preliminary Report on the Copper-bearing Rocks of Douglas County, Wisconsin. By ULYSSES SHERMAN GRANT, Ph.D. Wisconsin Geological and Natural History Survey, Bulletin No. VI. Economic Series No. 3, pp. 55. 1900.

The report is the result of field work during the summer of 1899, and deals in a preliminary way with the St. Croix and Douglas copper ranges of Douglas county, Wisconsin. It contains four geological maps and several illustrative plates. Chapter I outlines the geology of the county and contains a sketch of the three rock series represented; namely, the Cambrian, the Upper Keweenawan, and the Lower Keweenawan. The Lower Keweenawan consists of igneous rocks, largely basic lava flows with a few interbedded conglomerates. The copper deposits are usually at or near the contacts of the flows, and the author has given some of the characteristics by which the contacts may be known. The Upper Keweenawan consists of conglomerates, sandstones and shales, lying apparently conformably upon the igneous beds and dipping southeast at low angles. The Lake Superior sandstone underlies the northern part of the county, and consists essentially of quartz sand, but in some places becomes conglomeratic, and in others clayey or shaly. Its junction with the Lower Keweenawan is marked by a fault of considerable displacement along which the traps are shattered. Chapter II describes some of the more important outcrops of the St. Croix range and chapter III treats the Douglas range in a similar manner.

The last chapter is a "brief discussion concerning the mode of occurrence of the copper, where to search for copper, and the value of the deposits." This chapter is of special value to the prospector and the investor. On pages 53 and 54 are given several analyses of copper-bearing rocks from the two ranges. R. D. GEORGE.

Upper and Lower Huronian in Ontario. By ARTHUR P. COLEMAN. Bulletin of the Geological Society of America, Vol. XI, pp. 107–114. 1900.

In his work as geologist for the Ontario Bureau of Mines the author has gathered much material bearing on the problem of the Huronian in Ontario. In tracing the Michipicoten iron range it was found that the band of siliceous rock associated with it, and generally resembling

sandstone, passes at times into cherty and jaspery and quartzitic facies. The same association of siliceous rock and iron ore is found near Pic River, near Rainy Lake and on Rainy River, and near Rat Portage. Jaspery material like that of Michipicoten is found interbedded with iron ores near Lakes Wahnapitae and Temagami, between Sudbury and the Ottawa River. "If, as seems probable, these jaspers are the equivalents of the western Huronian sandstones, we have a definite horizon, traceable from point to point across the whole northern end of the province" which will be "a most valuable thread with which to unravel the much disturbed and complicated series of Huronian in Ontario." The conglomerates frequently found near the iron-bearing series and containing sandstone, chert, or jasper, identical with those of the iron-bearing series, have a similar range from east to west across the province and are thought to mark the greatest break in the Huronian series, or, in other words, to form the basal conglomerate of the Upper Huronian.

The author shows that if these conclusions are well founded we have "a means of correlating the widely separated and very different looking rocks mapped as Huronian in Ontario. Applying these conclusions to the Shoal Lake district, a part of Lawson's Keewatin is of Huronian age. They may also lead to a more certain correlation of the pre-Cambrian rocks of Ontario and the Wisconsin-Minnesota region."

R. D. GEORGE.

Mesozoic Fossils of the Yellowstone National Park. By T. W. STANTON. An extract from "Geology of the Yellowstone National Park," Monograph XXXII of the U. S. Geological Survey, Part II, Chapter XIII. Washington, 1899.

This chapter forms a valuable contribution to our knowledge of the Mesozoic faunas. The collection of invertebrate fossils described in it consists of seventy-eight species, having a distribution as follows: thirty-one are Cretaceous, forty-six are Jurassic, and one is possibly of Triassic age. The last specimen, a species of *Lingula* resembling *L. brevirostris* of Jurassic age, occurs in the Teton formation which occupies the stratigraphic position between the known Carboniferous and the undoubted Jurassic. This paleontologic evidence is considered too slight to form the basis of a correlation of the Teton with the Triassic of other areas.

The Jurassic assemblage forms the most important element of the collection. The two chief fossiliferous areas are: the one in the northwest corner of the Park, on the head waters of the Gardiner and Gallatin Rivers; and the other on the slopes of Sheridan Peak and farther southwest of Snake River. Two zones, characterized more by lithological than faunal peculiarities, are to be recognized, but the fossils belong to a single fauna.

The upper zone is marked by an arenaceous limestone yielding an abundance of *Rhynconella gnathophora*, *R. myrina*, *Ostrea strigilecula*, *Camptonectes bellistriatus*, and *C. pertenuistriatus*. The lower zone is characterized by calcareous clays and marls containing the majority of the above forms associated with *Pleuromya subcompressa*, *Pholadomya kingi*, and *Gryphea calceola* var. *nebrascensis*.

I found very similar zones in the Freeze-Out Hills of Wyoming, but they were characterized by slightly different assemblages of fossils. The upper zone consisted of clays and arenaceous limestones containing *Pentacrinus astericus* in abundance, and *Asterias dubium*, *Camptonectes bellistriatus*, *C. (extenuatus) pertenuistratus*, and *Ostrea strigilecula*. In the lower zone occurred clays and marls with calcareous nodules yielding *Astarte packardi*, *Pinna kingi*, *Pleuromya subcompressa*, *Pholadomya kingi*, and other forms. *Belemnites densus* and *Pentacrinus astericus* is common to both zones.

As these zones are both extremely narrow, are composed largely of clastic material, and contain an assemblage of fossils in many instances common to both, I think the conclusion that but a single fauna is represented is the correct one. This conclusion in regard to the Yellowstone region Dr. Stanton extends to the entire Jurassic formation of the Rocky Mountain region, and concludes as follows: "The stratigraphic relations and the geographic distribution of the marine Jurassic of the Rocky Mountain region are in favor of the idea that all of these deposits were made contemporaneously in a single sea."

A thin stratum of limestone in a position above the Jurassic beds and not far below the base of the Cretaceous section contains fresh water gastropods and Unios. The formation which contains this limestone is referred with considerable doubt to the Dakota. It is thought that it may be the equivalent of the Kootenai or Como. A similar limestone stratum occupying approximately the same stratigraphic position is found in the Como of Wind River, of the Black Hills, and the writer found it also in the Freeze-Out Hills. In all these localities

it contains a fresh water fauna consisting of gastropods and Unios, and in some instances species common to two or more localities.

The Colorado formation is represented by a characteristic fauna, consisting for the most part of Inocerami. The Montana formation is recognized, but its divisions are not easily differentiated. It seems probable that only the lower part of the Montana is represented.

In all, thirteen new species are figured and described. The majority of these belong to the Jurassic.

W. N. LOGAN.

The Glacial Gravels of Maine and their Associated Deposits. By GEORGE H. STONE. Monograph XXXIV, U. S. Geological Survey, 499 pp., 52 plates, 36 figures. Washington, 1899.

The enthusiastic pursuit of kames and eskers through the forests of Maine without official aid, in the later seventies, by Professor Stone, led to his engagement for a monographic study of all the glacial gravels of that phenomenally rich region by the U. S. Geological Survey. The results appear in this monograph. It would be an error, however, to overlook the second half of the title, for much attention is given to the formations associated with the glacial gravels, and tributary to their formation, so that the volume falls little short of being a monograph on the Pleistocene deposits of Maine.

So far as present knowledge extends, two regions surpass all others in the richness of their esker or osar phenomena—Maine on this continent, and Sweden on the eastern. This singular distribution is perhaps due to a critical relation between the general slope of the land surface in these regions and the minimum gradient at which glacier ice flows effectively, so that a condition of approximate stagnation was assumed in the closing stages of glaciation and the internal drainage lines of the ice sheet were permitted to develop with exceptional facility. However that may be, Maine is certain to be the classic field for esker studies in this country.

The plan of the volume embraces a preliminary discussion in which the fundamental facts of surface geology as illustrated in Maine are set forth with considerable fullness (chapters I, II, and III). The operative agencies are discussed in close connection with the phenomena described. This is followed by a general description of the systems of glacial gravels (chapters IV, and V). By systems is to be understood

those connected series of gravel ridges that are interpreted as the products of individual drainage systems of the ice sheet, the products of each river system being a gravel system. Some forty odd systems of this kind are recognized besides several less defined series and numerous branches and individual eskers, making on the whole a most phenomenal record of glacial drainage. The description of these occupies 170 pages.

The classification of the gravels and associated deposits and a discussion of their genesis follows and constitutes essentially the remainder of the volume (chapters V and VI, 224 pages). The discussion of the genetic element is elaborate and detailed. Something of the range of special subjects may be gathered from the following special themes: Quantity of englacial débris; distinction between englacial and subglacial tills; the origin of drumlins; the relations of the marine gravels; bowlder fields and bowlder trains; single or multiple glaciation in Maine; the relation of the glacial waters to the glacial sediments; the sizes of the glacial rivers of Maine; the zones of the Maine ice sheet; englacial streams; the directions of subglacial and englacial streams under existing glaciers; the internal temperatures of ice sheets; the basal waters of ice sheets; basal furrows as stream tunnels; the genesis and maintenance of subglacial and englacial channels; the forms of glacial channels; extraordinary enlargements of glacial river channels; the directions of glacial rivers compared with the flow of ice; the relations of glacial rivers to the relief forms of the land; sedimentation in places favorable or unfavorable to the formation of crevasses; glacial potholes; the formation of kames and osars; the bowlders of the glacial gravels; comparative studies on the glaciation of the Rocky Mountains and on the glaciers of Alaska; the modification of the glacial gravels by the sea; the short isolated osars or eskers; the hillside osars or eskers; the isolated kames or eskers ending in marine deltas; isolated osar-mounds not ending in marine deltas; the disconnected osars; the relations of glacial gravels to the fossiliferous marine beds; retreatal phenomena of the ice; causes of non-continuous sedimentation within the ice channels; the continuous osars and their comparison with discontinuous osars; were osars formed by subglacial or superglacial streams? tests of subglacial and superglacial depositions; special features and their explanation.

The illustrations are numerous and add greatly to the value of the text, and the large list of maps set forth the remarkable distribution of the gravel systems.

The work is characterized by enthusiasm and a pervasive desire to explain in fullness and detail all of the phenomena presented. The observational and the rational go hand in hand and each lends interest to the other.

T. C. C.

Lower Cambrian Terrane in the Atlantic Province. By C. D. WALCOTT, Proceedings of the Washington Academy of Sciences. Vol. I, pp. 301–339. February 14, 1900.

The object of the paper, as stated by the author, is to show the stratigraphic relations and successions of the Cambrian faunas of the Atlantic province. In the author's correlation paper on the Cambrian (Bull. 81, U. S. Geol. Surv. 1891), reference is made to unsolved problems of the Cambrian of this province. Mr. G. F. Matthew's study of these problems has led him to conclusions not in accord with those tentatively set forward by Mr. Walcott. He finds the Etcheminian beds at Hanford Brook unconformably below the Protolenus zone and regards them as a pre-Cambrian Paleozoic terrane, and makes a twofold division of the Cambrian of the Atlantic province as follows:

Upper Cambrian, - - -	Dictyonema fauna. Peltura fauna. Olenus fauna.
Lower Cambrian, - - -	Paradoxides fauna. Newfoundland species described. Protolenus fauna.

Mr. Walcott, having made a careful study of the Hanford Brook and other localities cited by Mr. Matthew in support of his position, notes the absence of Etcheminian débris in the overlying St. John quartzite, the absence of an irregularly eroded surface on the Etcheminian beds, and the evidence of overlap of these beds on the subjacent Algonkian, and holds that the patchiness and variation in thickness of the Etcheminian may be the result of deposition of sediments upon a very irregular sea-bottom, and not of erosion as held by Mr. Matthew. Mr. Walcott believes the distinctive features of the Etcheminian fauna pointed out by Mr. Matthew do not necessarily separate it from the

Lower Cambrian. The paper closes with the following conclusions:

"(*a*) The 'Etcheminian' terrane of Matthew is of Lower Cambrian age.

"(*b*) The Olenellus fauna is older than the Paradoxides and Protelenus fauna of the Middle Cambrian.

"(*c*) The Cambrian section of the Atlantic Province of North America includes the Lower, Middle, and Upper Cambrian divisions as defined by me in 1891."

R. D. GEORGE.

Forest Reserves. Part V of the Nineteenth Annual Report of the United States Geological Survey. HENRY GANNETT, Chief of Division, Washington, D. C., 1899.

This report consists of the following parts: The forests of the United States, by Henry Gannett; Black Hills Forest Reserve, by H. S. Graves; Big Horn Forest Reserve, by F. E. Town; Teton Forest Reserve, from notes by F. S. Brandegee; Yellowstone Park Forest Reserve, from notes by F. S. Brandegee; Priest River Forest Reserve, by J. B. Leiberg; Bitterroot Forest Reserve, by J. B. Leiberg; Washington Forest Reserve, by H. B. Ayers; Eastern Part of Washington Forest Reserve, by M. W. Gorman; San Jacinto Forest Reserve, by J. B. Leiberg; San Bernardino Forest Reserve, by J. B. Leiberg; San Gabriel Forest Reserve, by J. B. Leiberg: Forest conditions of Northern Idaho, by J. B. Leiberg; Pine Ridge Timber, Nebraska, by N. H. Darton.

According to the report there are in the United States, exclusive of Alaska, 1,094,496 sq. miles of wooded land, or in other words 37 per. cent of the total area is wooded. The total value of the forest product of the country for 1890 was 800 million dollars which is an amount slightly in excess of its mineral production. The total amount of sawed lumber consumed was 23,500 million feet B. M., and the amount used for fuel was 180,000 million feet B. M.

The sources of injury to forests are classed under the categories of fires, winds, lightning, insects, and wasteful methods of lumbering. The necessity for better forest management is urged in order to prevent waste, and to establish forests in the place of those being depleted for legitimate purposes. It is urged that the object of forest management should be to produce forest products in as short a time

as possible, to establish if possible a system of forestry which will produce lumber timber in less than 150 years, and mine timber in less than 100 years.

The principal subjects discussed in the several divisions of the report embrace the topography, the limits, the agricultural lands, the mining and the forests of the reserves. Other topics include the water supply, parks species of timber, classification of timber, amount of available timber, and means of transportation of lumber.

The report is furnished with an excellent set of illustrations and maps. It is a valuable contribution, well calculated to accomplish the purposes for which it was written, *i. e.*, to furnish as full data as possible concerning our forests, and to waken a desire for their preservation.

W. N. LOGAN.

Geology of Narragansett Basin. By N. S. SHALER, J. B. WOODWORTH and A. F. FOERSTE. Monograph XXXIII, U. S. Geological Survey, pp. xx + 394. 1900.

The Monograph is divided into: Part I, General Geology of the Narragansett Basin, by N. S. Shaler; Part II, Geology of the Northern and Eastern Portions of the Narragansett Basin, by J. B. Woodworth, and Part III, Geology of the Carboniferous Strata of the Southwestern Portion of the Narragansett Basin, with an account of the Cambrian deposits, by Aug. F. Foerste.

The stratified rocks of the basin range from Cambrian to Carboniferous. The structure of the basin makes it appear probable that it originally contained an extensive development of pre-Cambrian rocks. Upon these were laid down the lowest Cambrian beds. The Middle Cambrian is not represented in the region south of Braintree. The Upper Cambrian is represented only by pebbles of quartzite in the conglomerates. While only the Lower Cambrian is found in situ, pebbles of Middle and especially of Upper Cambrian are so abundant as to lead to the statement that "there appears to have been nearly continuous deposition in this field throughout the Cambrian period." The Silurian and Devonian do not appear to be represented in the Narragansett Basin. Upon the Cambrian strata and the eruptive granites come the Carboniferous strata which occupy the greater part of the basin. It is probable that the earliest Carboniferous rocks of the basin are the upper part of the Coal Measures, and it is possible that the upper conglomerates of the basin may be Permian. The basin was probably

partly formed before Carboniferous time. Professor Shaler believes that east of the Appalachians there were developed during Carboniferous times a great series of erosion troughs which by sedimentation and subsidence became centers of quaquaversal orogenic movement, resulting in foldings with axes variously inclined to one another within the same trough. The truncated remains of the folds so produced are to be seen at various points along the Atlantic seaboard. That these erosion troughs were river valleys and estuaries is suggested by their lack of parallel or other definite arrangement such as is seen in the Appalachians, as well as by the character of the deposits they contain. The Narragansett basin is one of these ancient erosion troughs in which the folds were of the anticlinal and synclinal type. The present average structural depth of the basin is placed at 7000 feet, but it is assumed that this depth is due mainly to folding resulting from accumulation of deposits. The source of the bulk of the sediments of the basin was the immediately surrounding granitic, trappean, schistose and other rocks. There are also many quartzitic pebbles of Cambrian age in the conglomerates but the source of the similar pebbles of the drift is considered unsettled. In discussing the glacial history of the region Professor Shaler expresses the view that this district was one of extensive and long continued glaciation during the Carboniferous period and that the important features of the upper stratified rocks are due to glacial action.

In the economic section the soils, coals, and iron ores are discussed at considerable length. Recent subsidence in the immediate vicinity of the basin has caused flooding of old valleys. This and the thick covering of drift have rendered geological work difficult, and the delimitation of formations uncertain. The volume represents much detailed work accomplished in a region presenting more than ordinary difficulties. There are many well placed plates and figures to illustrate the text.

R. D. GEORGE.

On the Lower Silurian (Trenton) Fauna of Baffin Land. By CHARLES SCHUCHERT. Proceedings of the U. S. National Museum. Vol. XXII, pp. 143–177, with plates XII to XIV.

At the request of the author, Mr. J. N. Carpender and others (who accompanied the Seventh Peary Arctic Expedition as far as Baffin Land in 1897,) made collections of fossils from Silliman's Fossil Mount at

the head of Frobisher Bay. The fossils are well preserved and many of them are now in the U. S. National Museum. The paper gives a brief summary of the geology of the region as gathered from reports by those who have either visited it or have examined collections from it. The Lower Silurian fossils so far collected are of Trenton and Utica age, and strata containing these faunas are widespread in eastern Arctic America. So far as known they rest upon the pre-Cambrian rocks and are overlain by beds of Niagara age. Of the 72 species known from the locality of Silliman's Fossil Mount 28 are restricted to it. Of the remaining 54 species, 41 are found in the Manitoba-Minnesota-Wisconsin region and 17 in the New York-Ottawa region. A comparison of the 54 species found elsewhere with those from definite stages in Minnesota shows that 10 are found in the Birds-eye (Lowville), 17 in the Black River, 38 in the Galena, and 11 in the Cincinnatian.

The close resemblance of the Minnesota Galena to the Silliman's Fossil Mount formation may in large part explain the close identity of the faunas. In the summary, page 175, the author says: "The Baffin Land fauna had an early introduction of Upper Silurian genera in the corals Halysites, Lyella and Plasmopora. In Manitoba similar conditions occur in the presence of Halysites, Favosites, and Diphyphyllum. The Trenton fauna of Baffin Land shows that corals, brachiopods, gastropods, and trilobites have wide distribution and are therefore less sensitive to differing habitats apt to occur in widely separated regions. On the other hand the cephalopods and particularly the pelecypods, indicate a shorter geographical range. The almost complete absence of Bryozoa in the Baffin Land Trenton contrasts strongly with the great development of these animals in Minnesota and elsewhere in the United States."

The paper is a valuable addition to our knowledge of the Ordovician faunas of eastern Arctic America.

R. D. GEORGE.

The Freshwater Tertiary Formations of the Rocky Mountain Region. By W. M. DAVIS. Proceedings of the American Academy of Arts and Sciences, Vol. XXXV, No. 17, March, 1900.

In this very timely paper Professor Davis gives voice to a growing change of opinion regarding the specific mode of origin of the most

characteristic class of formations of the Rocky Mountain Tertiaries. During recent years not a few geologists, here and there, have expressed a disposition to regard some of the deposits usually assigned to lakes as the products of stream action or "sheet wash," or of a combination of these with lake deposition. To the reviewer, who is among these dissenters, the favorite illustration of such modes of deposition is the present and recent accumulation in the Great Valley of California where several forms of subaërial aggradation are conjoined with lacustrine and marine deposition. This newer mode of interpretation has been applied to a notable series of formations distributed at intervals from the Medina, and even the Keweenawan, to the Lafayette and the recent deposits of the great basins of all the continents, particularly the arid basins. The great red terranes, with their associated products of desiccation and saline concentration, especially, have seemed to the reviewer attributable to such combined action, since a basin of saline concentration carries in its very terms the idea of a basin of detrital lodgment whose central part may be an area of subaqueous deposition but whose border is almost inevitably a zone of subaërial accumulation. The doctrine of non-lacustrine basin-aggradation, as it lies in the mind of the reviewer, has its most distinctive application[1] to tracts of relative aridity, for it is in these, chiefly, that the conditions of subaërial lodgment preponderate over the conditions of subaqueous deposition, except in the case of aggrading river bottoms near base level which are undergoing a depression of gradient by deformation. In an arid basin-tract the precipitation is likely to be greatest on the elevated rim, and there it is often spasmodic, taking the form of cloudbursts and similar intensified forms. The gradient is also highest, as a rule, in the rim zone. These form a combination of agencies which result in an exceptional transportation of detritus down the slopes of the basin rim followed by a marked reduction of power of transportation as the flatter part of the basin is reached; for there the flood loses its power by lowered gradient, by spreading, by absorption, and by evaporation. Deposition is the usual consequence. In a humid region, the conditions are largely reversed; the streams augment in volume as they flow over the basin-plain and the power of transportation is more or less fully maintained. If the basin be a closed one the accumulated waters arising from the excess of precipitation over evaporation soon cover the basin floor with a lake which occupies the territory that in an arid region would be

covered in large part with subaërial detritus. In a humid region with free drainage no great thickness of detritus can usually be built up on the floor of a basin without increasing the gradient so as to suspend the process of aggradation, unless movements of deformation or changes of sea-relationship intervene to renew and perpetuate the conditions of aggradation. This of course may happen, but it is rather to be classed as an accidental intervention than as a systematic process.

The presumptions therefore seem to lie on the side of lacustrine deposition, with incidental fluvial aggradation, in humid regions, while in arid regions they lie on the side of fluvial aggradation, with incidental lacustrine deposition. To the reviewer, therefore, the question has a specific climatic relationship and this relationship seems much the most important phase of the subject. Given the same humidity, and the ratio of lacustrine to fluvial deposition is dependent on surface adjustments of a local nature. Given the same surface adjustments, and the ratio of lacustrine to fluvial deposition is dependent on states of humidity or aridity. But the humidity or the aridity of an area large enough to have geological importance, implies atmospheric states that are a function of the whole atmosphere, and of its modes of circulation, and hence has far-reaching significance.

If these considerations have any validity, the question which Professor Davis pointedly raises regarding the Rocky Mountain Tertiaries, as a specific example of the class under question, deserves the most critical attention. The value of an academic discussion, which is often unwisely underrated by the working field geologist, lies chiefly in deploying the problem and laying the groundwork for discriminative observations. Professor Davis seems to be altogether correct in pointing out a lack of critical observation and interpretation in most previous studies of the Tertiaries in question, and his discussion can hardly fail to call forth incisive studies upon these formations. Obviously their true character can only be determined by such critical field studies. A first step is the establishment of criteria of discrimination between lacustrine and fluvial deposits; by no means an easy task where the products of relatively shallow lakes are to be distinguished from those of rivers, which is really the critical case. It is not clear that the criteria given in the paper will always hold good, but there are several additional ones that may be brought into service, such as the distribution of the remains of land animals in the midst of

the basin, the occurrence of marsh-formed or land-formed lignites in similar situations, the interstratification of beds of gypsum or other desiccation products, and analogous criteria that imply aërial conditions. T. C. C.

The Crystal Falls Iron-Bearing District of Michigan. By J. MORGAN CLEMENTS and HENRY LLOYD SMYTH, with a chapter on the Sturgeon River Tongue by William Shirley Bayley and an Introduction by Charles Richard Van Hise. U. S. Geological Survey. Monograph XXXVI. Washington, 1899.

This report is the third in a series of four monographs on the iron-bearing district of the Lake Superior Region. Two having been published previously: one on the Penokee district (Monograph XIX). The other on the Marquette district (Monograph XXVIII). The fourth, on the Menominee district, is to follow.

The Crystal Falls district was divided areally, the western half being studied by Mr. Clements and the eastern half by Mr. Smyth, and the Sturgeon River Tongue by Mr. Bayley. The investigation was conducted under the charge of Mr. Van Hise, who sums up the general results in an introductory chapter. The district embraces 840 square miles. As pointed out in the introduction the rocks belong to the Archean and Algonkian. The latter consisting of a Lower Huronian and an Upper Huronian separated by unconformity. The Archean is believed to be wholly igneous in origin, it occupies a broad area in the eastern part of the district and has not been closely investigated. Several smaller areas occur within parts of the region carefully studied. Owing to the readily decomposable nature of the rocks in places and to the drift mantle the detail character of the formations is unknown for part of the area described by Clements, and in the belt worked by Smyth the rock surface is almost wholly concealed by glacial deposits and vegetation. It will be seen under what adverse circumstances the field work was carried forward, and how much credit is due the geologists who have brought to light so much valuable information from so unpromising a region.

The Lower Huronian consists of quartzite, dolomite, slate, a volcanic formation, and some schists. The series has a minimum thickness of 2200, and a possible maximum thickness of 16000 feet. The sediments probably nowhere exceed 5000 feet in thickness. The Upper Huronian

is a great slate and schist series, not separable into individual formations, and whose thickness cannot be approximately estimated. All of these formations have been cut by igneous rocks of various kinds and at different epochs.

Metamorphism has greatly altered the character of the Algonkian rocks. In the Lower Huronian the quartzite is the altered form of a sandstone and conglomerate in which the pebbles have been nearly destroyed. It is in places schistose. The dolomite is a nonclastic sediment. The slate or schist is an altered mudstone. The volcanic formation is perhaps the most characteristic feature of the Crystal Falls district. It occupies a larger area than the other Lower Huronian formations and consists of basic and acid rocks, lavas and tuffs, with subordinate interbedded sedimentary rocks. The iron-bearing formation, called the Groveland, consists of sideritic rocks, cherts, jaspillites, iron ores, and other varieties characteristic of the iron-bearing formations of the Lake Superior region.

After elevation and unequal erosion of the Lower Huronian, conditions of deposition covered these formations with sandstone and slate conglomerate, passing upwards into shales and grits, subsequently altered to mica-slates and mica-schists. These were followed by combined clastic and non-clastic sediments, the latter including iron-bearing carbonates. Above these is a great thickness of mica-slates and mica-schists.

After a long period of deposition a profound physical revolution occurred, raising the region and folding it in a most complex manner. The folds have steep pitches indicating great compressive stresses in all directions tangential to the surface of the earth. Subsequent to or during the late stage of this time of folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan, intruding within the rocks vast bosses and numerous dikes of peridotites, gabbros, dolerites and granites. These intrusives, while altered by metasomatic changes, do not show marked evidence of dynamic metamorphism.

Subsequently the region was subjected to great denudation and reduced approximately to its present configuration. In late Cambrian time Upper Cambrian sediments were deposited upon it. Whatever may have been deposited upon the Cambrian has been removed by erosion together with most of the Cambrian. If the region was again submerged in Cretaceous times no evidence of the fact remains.

During the Pleistocene period a thick mantle of glacial deposits was spread over the entire area, which has been eroded far enough to uncover the rocks here and there.

Clements's description of the western part of the district treats of the surface features, the economic resources and the petrographical character of the various formations, especial attention being paid to the volcanic rocks. The great abundance of volcanic breccias and tuffs indicates the probable existence in Huronian time of a volcanic cone in this region, but the possible location of its vent has not been discovered. A small part of the igneous rocks are acid, their area being too small to map on the scale of publication. They include rhyolite-porphyries and aporhyolite-porphyries and breccia of the latter. The great part of the volcanics are metabasalts and breccias of the same. An interesting development of ellipsoidal structure is noted. The pre-Cambrian intrusive rocks include granites and rhyolite-poryhyry, metadolerite, meta-basalt and picrite-porphyry, besides a series considered to be closely connected genetically ranging from granite, tonalite and quartz-mica-diorite through diorite, gabbro, and norite to peridotite. The diorite is closely related to monzonite.

In the second part of the monograph Smyth discusses at length the effect of buried magnetic ores on the magnetic dip needle, describes its use and the results of careful observations in locating the iron-bearing deposits. He also describes the different formations structurally and petrographically. The same is done by Bayley for the Sturgeon River Tongue.

J. P. I.

The Geography of Chicago and its Environs. By ROLLIN D. SALISBURY and WILLIAM. C. ALDEN. Bulletin No. 1 of the Geographic Society of Chicago, published by the Society. Chicago, 1899. 64 pp.

This pamphlet is a model essay on local geography written in an interesting style and illustrated in an attractive and instructive manner. From the maps and descriptions it is learned that Chicago is situated on a plain which stretches from Winnetka, sixteen miles north, to Dyer, about twenty-eight miles south of Chicago, and sweeps eastward around the southern end of Lake Michigan. This plain is narrower at its extremities and has a maximum width of fifteen miles in about the latitude of Chicago; it is limited on the east and northeast by Lake

Michigan, on the west and southwest generally by the Valparaiso moraine which loops around the southern end of Lake Michigan, through northern Indiana into Michigan. The plain topography is varied by three prominent "islands:" Stony Island, a drift-covered, dome-shaped hill of Niagara limestone with quaquaversal dip; Blue Island, a single morainic ridge about six miles long and fifty feet above its surroundings; and Mt. Forest Island, a portion of the Valparaiso moraine about 120 feet higher than the plain, separated from the rest of this moraine by the Chicago outlet. The plain is continued through the Valparaiso moraine southwest of Chicago by the Chicago outlet, which is divided by Mt. Forest Island into the Sag outlet and the Des Plaines outlet. The Des Plaines outlet is now followed by the Chicago Drainage Canal. Several less conspicuous gravel and sand beach ridges converging toward the Chicago outlet from the northeast and southeast help to break the monotony of the plain. On these ridges are oak groves, which have apparently suggested the names for the towns Oak Park, Oak Lawn, Englewood and others. The eastern third of the plain is largely made of gravel and sand. With the exception of the beach ridges, the western two thirds is largely of till. These deposits vary in depth from 0 to 130 feet. The country rock is Niagara limestone which has an elevation varying from 124 feet below the lake level to about 20 feet above it in Stony Island, and 100 to 110 feet above it under the Valparaiso moraine. The southeastern edge of the plain is occupied by a series of small lakes, the basins of which are in large part made by enclosing beach ridges. At the south end of Lake Michigan there are sand dunes with a maximum height of 100 to 200 feet. Other smaller dune areas exist nearer the city.

The main recorded events in the geographical history of the region since Devonian times are: (1) Withdrawal of the sea and destruction of formations younger than the Niagara with the exception of some fossiliferous Devonian material preserved in joints of the Niagara formation; (2) invasion of the ice in the glacial period, rounding off the angularities of the rock surface and probably diminishing the relief of the region by deposits of drift. At a late stage of the ice invasion the Valparaiso moraine was made. (3) As the ice edge retreated from the Valparaiso moraine a lake accumulated in the depression between the ice front and the moraine until the water stood at an elevation sixty feet above the present Lake Michigan when it overflowed to the west through the valley of the Des Plaines River and through the Sag outlet. To

this lake Mr. Leverett has given the name Lake Chicago. The stages in the history of this lake are as follows:

(*a*) Glenwood stage, the highest stage, when the level was sixty feet higher than Lake Michigan is now. During this stage the outlet was cut down twenty feet.

(*b*) A stage of recession, when discharge through the Chicago outlet ceased and the water withdrew from the Chicago plain in part or entirely. During this stage deposits of peat accumulated.

(*c*) Calumet stage, in which the water again discharged through the Chicago outlet at a level forty feet higher than the present level of Lake Michigan. During this stage the Calumet beach was formed over the peat deposits of the preceding stage.

(*d*) The lowering of the outlet gradually reduced the level of the lake twenty feet when the Tolleston beach was formed.

(*e*) A lower outlet was opened to the north and the lake fell below the level of the Chicago outlet. This closed the history of Lake Chicago and inaugurated that of Lake Michigan. Between the Tolleston beach and the shore of Lake Michigan there is an extensive series of sand and gravel ridges among which lie the small lakes mentioned above.

Abundant evidence of fresh water life has been found in the deposits of the Tolleston stage of the lake, but not in the deposits of earlier stages. On the surface of the Calumet beach, however, marine shells of southern species have been found, which may have been introduced artificially.

The bulletin is essentially a popularized version of the work of the United States Geological Survey and is a tribute to the value of its investigations. It is to be hoped that this bulletin will stimulate the publication of similar essays on local geography elsewhere. Interest in geography is certainly increased by such publications.

CHARLES EMERSON PEET.

Recent Publications

—Alabama, Geological Survey of. Report on the Warrior Coal Basin. With fifty figures in text, seven plates and one map. By Henry McCalley, Assistant State Geologist.

—Agassiz, Alexander. Explorations of the "Albatross" in the Pacific. Reprinted from the American Journal of Science, Vol. IX, January, February, March, and May numbers.

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—Bennett, C. W. Coldwater, Mich. The Ice Age and What Caused It. Published serially in the Michigan Miner, May-June 1900.

—Darton, Nelson H. Preliminary Report on Artesian Waters of a Portion of the Dakotas. Extract from Seventeenth Annual Report of the U. S. Geological Survey, 1895-6, Part II, Economic Geology and Hydrography. Washington, 1896.

—Emerson, Benjamin K. The Tetrahedral Earth and the Zone of the Intercontinental Seas. Annual Presidential Address. With an Appendix. The Asymmetry of the Northern Hemisphere. Bulletin Geological Society of America, Vol. II, pp. 61–106. Pls. 9–14. Rochester, March 1900.

—Grabau, Amadeus W. Siluro-Devonic Aspect in Erie County, New York. Bulletin Geol. Soc. of Amer., Vol. XI, pp. 347–376. Pls. 21–22. Rochester, May 1900.

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—Hayford, John F. Inspector of Geodetic Work, U. S. Coast and Geodetic Survey. The Transcontinental Triangulation under the 39th Parallel. Bull. University of Wisconsin, No. 38, Engineering Series, Vol. II, No. 5, pp. 173–194. Pls. 1–5. Madison, June 1900.

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Twentieth Annual Report, 1898–9, Part I, Director's Report, Triangu-ation and Spirit Leveling. Part VI, Mineral Resources of the United States, 1898. Metallic Products and Coke. Part VI continued, Mineral Resources of the United States, 1898, Non-Metallic Products except Coal and Coke.

Monograph XXXII, Part II, Geology of the Yellowstone National Park. Descriptive Geology, Petrography, and Paleontology. Hague, Iddings, Walcott, Stanton, Weed, Girty, Knowlton.

Monograph XXXIII, Geology of the Narragansett Basin. Shaler, Woodworth, Foerste.

Monograph XXXIV, Glacial Gravels of Maine and other Associated Pleistocene Deposits. Stone.

Monograph XXXVI, The Crystal Falls Iron-Bearing District of Michigan, with chapter on the Sturgeon River Tongue. Clements, Smyth, Bayley, Van Hise.

Monograph XXXVII, Fossil Flora of the Lower Coal Measures of Missouri. White.

Monograph XXXVIII, The Illinois Glacial Lobe. Leverett.

—YAHE, H. The Brachiopod Lyttonia from Rikuzen Province. Reprinted from the Journal of the Geological Society, Tōkyo, Vol. VII, No. 79, Japan, April 1900.

THE

JOURNAL OF GEOLOGY

JULY—AUGUST, 1900

IGNEOUS ROCK-SERIES AND MIXED IGNEOUS ROCKS

I. IGNEOUS ROCK-SERIES

By an igneous *rock-series* we may understand an assemblage of rock-types, differing perhaps widely but still with a certain community of characters, associated in the same district and belonging to the same suite of eruptions, and further, holding a similar position in the scheme of igneous rocks belonging to that suite. Adopting the differentiation hypothesis, we may conceive them as derivatives of the same order from one common source, resulting from differentiation along similar lines and to the same degree. The fundamental characteristics of such a series, having regard to chemical composition, are of two kinds: (1) those belonging to the individual rock-types and shared by all the types included in the series (*e. g.*, each member is rich in some particular constituent, as compared with average igneous rocks of like silica-percentage); and (2) those belonging to the assemblage of types as a whole, depending upon variations in the composition of the members as compared with one another (*e. g.*, a particular constituent may in one rock-series fall off steadily with increasing silica-percentage, in another series it may rise to a maximum and then decline). These characteristics, and especially those which fall under the second head,

come out most clearly when exhibited graphically in a diagram such as was first used by Professor Iddings.[1]

The diagram is easily constructed from the analyses of the rocks (Fig. 1). Two rectangular axes, *OX* and *OY*, are drawn, horizontally and vertically, each of length equal to 100 parts of some convenient scale. We cut off the abscissa *OM* to represent the silica-percentage of any one of the rocks, and erect ordinates *MP*, *MQ*, etc., to represent the corresponding percentages of the other oxides, which we may conveniently speak of as the bases. This is done for each of the rocks. Then joining *P P'*. . . . ., etc., we have a line which represents the variation of one particular base in this rock-series, and similarly for the other bases. Iddings converts the figures of the analyses into molecular proportions before expressing them graphically; but for our present purposes nothing would be gained by doing this, and we may follow the simpler method.

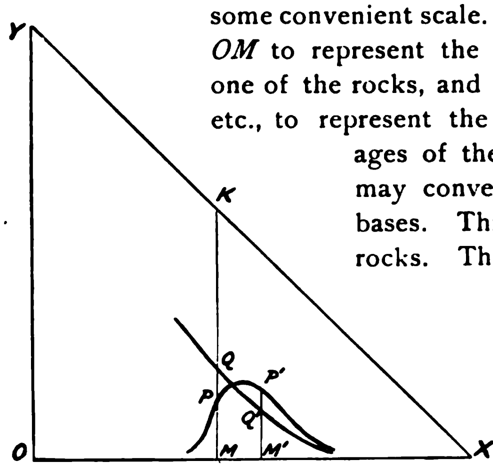

FIG. 1.

The lines *PP'*. . . . ., etc., *QQ'*. . . . ., etc., as thus laid down, are broken or zigzag lines. We find, however, that in a rock-series in the strict sense of Brögger the departures from regularity are not great. Minor irregularities may arise from the variation found among different specimens of the same rock-type, or from errors in the analyses. To obtain a clearer picture of the essential variations characteristic of the series it will be legitimate to *smooth* the lines, *i. e.*, to convert them into flowing curves passing as nearly as may be through the proper points. The diagram then affords a graphic representation of the chemical characteristics of the given rock-series. We may use it, for

[1] Origin of Igneous Rocks, Bull. Phil. Soc. Wash. (1892), Vol. XII, pp. 89–214.

example, to obtain by interpolation the chemical composition of a member of the series intermediate between two known members. To predict by extrapolation the composition of a hypothetical member beyond the limits covered by actual representatives is, of course, a more speculative matter, since we have no precise data for prolonging the empirical curves. There are, however, some obvious considerations. The sum of all the ordinates MP, MQ, etc., for a given rock must be equal to MK, K being the point in which the vertical through M meets the straight line YX. Hence all the curves must be contained within the triangle YOX : prolonged to the right, they must all meet at the point X, corresponding with a hypothetical rock with 100 per cent. of silica : prolonged to the left, they must meet the line OY in points such that the sum of all the ordinates is equal to OY, corresponding with a hypothetical rock devoid of silica.

The simplest kind of variation conceivable is found when, with increasing silica-percentage, the percentage of each base changes at a constant rate (different for each). In other words, the percentage of each base is then a linear function of the silica-percentage. Such a series may be termed a *linear series*, and its geometrical characteristic is that all the curves in the diagram become straight lines. In the wholly ideal case of a linear series extending to the ends of the scale, all these straight lines would decline towards the right and meet at the point X. It is safe to say that no such series exists in nature, nor has any natural series been described corresponding with a portion of such a diagram. It may, however be inquired whether, or to what extent, natural rock-series fulfill the condition of linearity within the limits of the actual representatives of the series. Professor Brögger, in his memoir on the grorudite-tinguaite-series,[1] makes approximate linearity a characteristic property of a *Gesteinsserie* : this is implied in his dictum "every mean of a number of members of the series corresponds approximately with a possible member of the series." But it is easy to show by plotting graphically the analyses which he gives that this

[1] Eruptivgesteine des Kristianiagebietes (1894), Part I, p. 175.

must not be understood in too literal a sense. Indeed, Brögger himself abandons the principle; for, in calculating by extrapolation the composition of a hypothetical end-member of the series, he supposes that, while some of the bases vary in arithmetical, others vary in geometrical proportion: a supposition inconsistent with linearity.[1] If a few rock-series be actually plotted in diagrams, it soon becomes apparent that, while some of the bases often give sensibly straight lines within the limits of the actual rocks, others give lines very decidedly curved. We may note in passing that some kinds of variation in igneous rock-masses connected with differentiation *in situ* involve much more considerable departures from the linear type. Such, for instance, is the "concentration" of the more basic constituents in certain parts of a rock-body, as investigated by Vogt and others.

It appears then that in general the diagram of a rock-series will consist of *curved* lines to indicate the variations in percentage amount of the several bases. Of these curves we may dis-distinguish two kinds: (*a*) When the constituent in question first increases to a maximum and then decreases, or increases first more rapidly and then less rapidly, or decreases first less rapidly and then more rapidly, the curve will be *convex* upward; (*b*) When it decreases to a minimum and then increases, or decreases first more rapidly and then less rapidly, or increases first less rapidly and then more rapidly, the curve will be *concave* upward. This classification is not an exhaustive one, for there may be curves which are inflected, being convex in one part and concave in another, but it will be sufficient to consider the simpler cases. Since the sum of the ordinates for all the bases falls off steadily in linear fashion, its curve of variation being the straight line *YX*, it follows that in any series, other than an ideal linear one, some of the bases must give convex and others concave curves.

II. MIXED IGNEOUS ROCKS

Considerable differences in composition may exist among members of the same rock-series, and still greater differences are

[1] *Ibid.*, p. 172.

found among members of different series belonging to the same suite of eruptions in one district. Most of those who have discussed the origin of igneous rocks have sought the cause of this diversity in various processes of diffusion, etc., commonly spoken of as *differentiation* in rock-magmas; it is no part of our present object to discuss these processes. Some geologists, however, including Professor Sollas and Dr. Johnston-Lavis, have laid stress on the possible origin of certain igneous rocks by *admixture*, a process in some sense the reverse of differentiation, and this question we shall consider more closely.

We may distinguish *a priori* three cases:

1. Mixture of two fluid rock-magmas.
2. Permeation or impregnation of a solid rock by a fluid magma with consequent reactions between the two.
3. Inclusion of solid rock-fragments (xenoliths of Sollas) in a fluid magma and their partial or total dissolution and incorporation in the magma.

In the first case the two rocks involved must be of the same age and presumably from a common origin. In the second and third cases this is not necessarily true, and the solid rock need not even be an igneous one; but, when we examine actual instances which have been described, it seems probable that here also admixture does not in fact take place on an important scale except between igneous rocks of cognate origin. Lacroix, in his exhaustive memoir on xenoliths,[1] distinguishes two categories, *enclaves énallogènes*, which are not related in composition or by origin to the enclosing rock (*e. g.*, limestone fragments in trachyte), and *enclaves homœogènes*, which do present more or less resemblance in composition and origin to the rock in which they are enclosed (*e. g.*, olivine-nodules in basalt). Similarity of mineralogical composition is, however, by no means a sufficient test of community of origin among igneous rocks, and instances may easily be cited (*e. g.*, some cases of gabbro enclosed in granite) which would be placed by Lacroix under the former of his two heads, but in which there exists, despite differences of

[1] Les enclaves des roches volcaniques, Macon, 1893.

composition, an essential and close relationship between the two rocks thus associated. Instead of using the above terms in an altered sense, it will be better to coin new ones, and we shall accordingly recognize two kinds of xenoliths, *accidental* and *cognate*. This distinction is based, not on difference or likeness in composition, but on the existence, in the latter kind, of a genetic relationship between the enclosed and the enclosing rock, which is wanting in the former kind. A like distinction will apply to the permeation of a solid rock-body by a fluid magma. Now although both permeation and the incorporation of xenoliths are known in instances which fall under the accidental category, they are known thus only as quite local phenomena. If new rocks of any considerable extent or importance are actually produced by admixture, it is by admixture of two cognate rocks. One reason for this is doubtless to be found in the consideration that reactions between a solid rock and a fluid magma will be promoted by the former being still at a high temperature when the latter comes into contact with it. There may be other reasons of a chemical nature.

Without discussing at once whether admixture is a factor of prime importance in the genesis of igneous rocks, we may inquire what kind of rocks are to be expected from such a mode of origin. We take first the simplest case, that of admixture between two members of the same rock-series. The chemical composition of the resulting product will be the same whether both or only one of the two rocks be fluid at the time when they are brought together. If the series be a linear one, the admixture will produce a rock having the composition of a possible member of the series. This is Brögger's principle already quoted, which, however, requires to be limited by the condition here imposed. In the more general case the mixed rock will not correspond with a possible member of the series, but will differ more or less in composition from that possible member which has a like silica-percentage. This is clear when expressed graphically (Fig. 2). If OM and OM' represent the silica-percentages of the two component rocks, and their proportions

in the mixture be a to b, then Om will represent the silica-percentage of the mixture, m being the point which divides MM' in the ratio b to a. (The empty portion of the diagram is omitted to save space.) If PpP' be the curve of variation of some one of the bases, then mp' in the figure represents the percentage of that base in the mixed rock. The percentage in the corresponding member of the rock-series is represented by mp, and the mixed rock is therefore deficient in this base as compared with the latter, the defect being represented by pp'. Similarly a different base, having QqQ' for its curve, will be in excess in the mixed rock as compared with the corresponding member of the rock series, the excess being represented by qq'. It is evident that there will be a defect or an excess according as the curve is convex or concave between the points corresponding with the two component rocks. The defect or excess will be greater, *ceteris paribus*, the farther apart the two component rocks are in the series. It is easy to see that, given a series such that its diagram has markedly curved lines, the result of the admixture of two members may be something not only foreign to the series, but highly peculiar by comparison with igneous rocks in general.

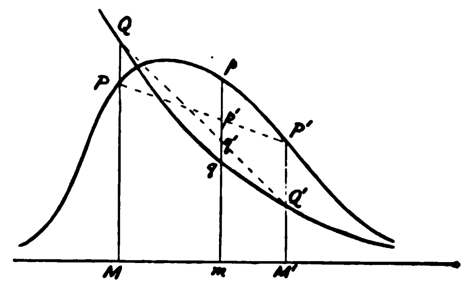

FIG. 2.

This may be still more strikingly the case in the admixture of two rocks which have no such close relation with one another. In illustration we take two simple cases of accidental xenoliths. First suppose a rock-magma to become enriched in silica by dissolving quartz, of extraneous origin, a parts of the magma taking up b parts of quartz. Dividing MX at m in the ratio b to a, we have Om to represent the silica-percentage of the resulting mixed rock (Fig 3). If MP, MQ, etc., represent the percentages of the various bases in the original magma, then mp', mq', etc., will represent them in the mixed rock, these ordinates being

cut off by straight lines joining the points P, Q, etc., to X. If we now draw curves such as Pp, Qq, etc., to indicate in a general way the usual behavior of the several bases in average igneous rocks, we obtain some idea of the respects in which the mixed rock is peculiar. In the diagram it is shown as being unusually poor in the first base and rich in the second. Next suppose a rock-magma to become enriched in lime by dissolving limestone, in the proportion of a parts of the magma to b parts of lime. The result is illustrated by the diagram, Fig. 4. The line OM is divided at m in the ratio a to b. If MP represents the lime in the original magma, mp' will represent that in the mixture, this ordinate being cut off by the straight line joining P to Y. If MQ and MR represent two other bases in the original magma, mq' and mr' will represent them in the mixture, these ordinates being cut off by straight lines joining the points Q and R to O. It is noteworthy that the mixture, as compared with ordinary igneous rocks, may be unduly rich in other bases besides lime: in the figure this is the case with the second of the two bases represented (curve passing through R).

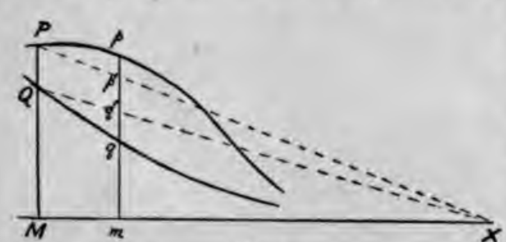

FIG. 3.

The foregoing general considerations lead us to anticipate that a rock resulting from admixture may be, and in many cases must be, of peculiar chemical composition. A rock-series, for example, may consist of basalt, pyroxene-andesite, dacite, and rhyolite; but it does not follow that a mixture of basalt and rhyolite will produce an andesite or a dacite. Still less will a basalt be converted into an andesite by addition of silica, or a rhyolite into a dacite by addition of lime. The processes by which different igneous rocks have been evolved from a common stock are too complex and subtle to be reversible, at least by so crude a method as that of admixture. To illustrate these remarks from

actual instances, we have only to take a collection of trustworthy rock-analyses, such as that published by Clarke and Hillebrand,[1] and plot diagrams upon a convenient scale. The lavas of the Lassen Peak region in California afford a good example. Here the curves of some of the bases approximate to straight lines throughout a considerable part of their extent. Towards the basic end, however, the alumina-line becomes strongly convex and those for magnesia and lime decidedly concave, while the soda-line is slightly but distinctly convex throughout. This diagram includes the normal basalts, andesites, dacites, and rhyolites; and the very slight amount of smoothing required to obtain flowing curves stamps this group of rocks as a natural series. The quartz-basalts, on the other hand, refuse to adapt themselves to this scheme, and their abnormal composition is clearly brought out by plotting their analyses on the same diagram. In their content of lime and potash they do not differ notably from normal rocks of like silica-percentage, but they show a marked deficiency in alumina and ferric oxide, and to a less degree in soda, and an excess of magnesia and ferrous oxide.

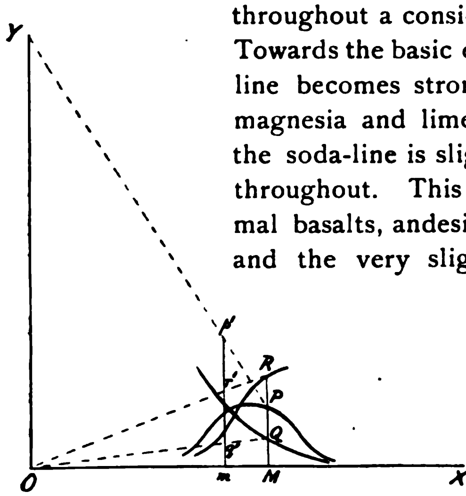

FIG. 4.

Although natural series of igneous rocks differ considerably from one another, they nevertheless possess certain broad characteristics in common. This is recognized by the very general practice of speaking roughly of acid, intermediate, and basic rocks, etc., as having more or less distinctive characters; which tacitly assumes that, in the broadest view, they fall approximately into a single line. Given a large number of analyses of normal (unmixed) igneous rocks, we might average the composition of those having like silica-percentages, and construct

[1] Analyses of Rocks, Bull. No. 148, U. S. Geol. Surv. 1897.

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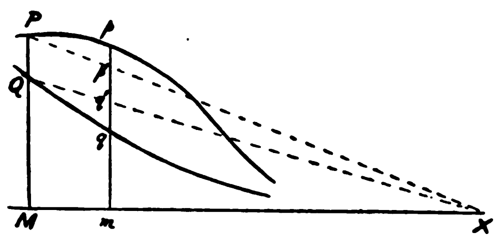

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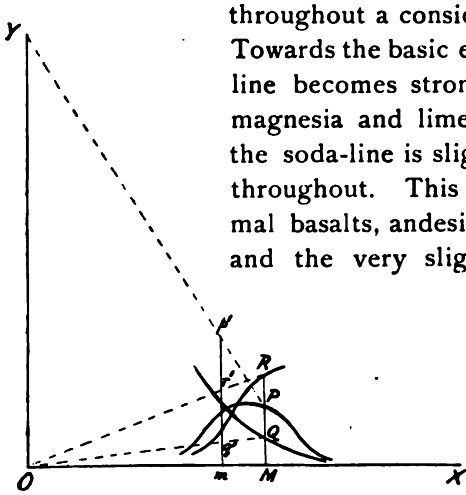

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Although natural series of igneous rocks differ considerably from one another, they nevertheless possess certain broad characteristics in common. This is recognized by the very general practice of speaking roughly of acid, intermediate, and basic rocks, etc., as having more or less distinctive characters; which tacitly assumes that, in the broadest view, they fall approximately into a single line. Given a large number of analyses of normal (unmixed) igneous rocks, we might average the composition of those having like silica-percentages, and construct

[1] Analyses of Rocks, Bull. No. 148, U. S. Geol. Surv. 1897.

from such averages a diagram expressing the variation of the several bases. Further, we might note the limits of variation of each base within each group averaged, and express these limits also on the diagram. Each base would therefore be represented, not by a simple curve, but by a curved band of varying width. A still further refinement would be to indicate, say by different depths of color within the bands, the frequency of different degrees of departure from the average. On such a diagram it would be possible to test with some precision the principle here advanced, that mixtures, even of two normal igneous rocks and still more of an igneous and a sedimentary rock, must often be abnormal in chemical composition.

So much labor is, however, not necessary for our present purpose. We have hitherto considered only the bulk analyses of the rocks; but we know that a close relation exists between the chemical composition and the mineralogical; a relation which is a matter of very nice adjustment. Expressing it in a crude empirical way, we may say that the chemical variation evinced in normal igneous rocks is not of an arbitrary kind, but is such that the rock-magmas have been able to crystallize as mineral-aggregates consisting of species selected from a comparatively small category, and selected subject to certain laws of paragenesis which control the permissible associations of those mineral species. In a natural assemblage of rock types, whether a "Gesteinsserie," a "Faciessuite," or any other kind of grouping, the limitations are of course narrower still. To inquire into the significance or rationale of such rules would be to enter upon a theoretical discussion of the processes of differentiation, a subject outside our scope: they are introduced here as affording in great measure a test for mixed igneous rocks. For it follows that any variation of an *arbitrary* kind (*i. e.*, not on the lines of magmatic differentiation) imposed on the *chemical* composition of an igneous rock-magma may produce much more considerable modification in the *mineral* composition of the resulting rock. It is well known that, when a magma has absorbed material from sedimentary rocks, this often results in the formation of such

minerals as cordierite, sillimanite, corundum, spinel, idocrase, and others, which are either quite foreign to normal igneous rocks or at least foreign to rocks of the general type of those concerned. A mixture of two igneous rocks will in general show less obvious peculiarity, but it may still be expected to betray itself in the occurrence of unusual minerals, unusual mineral-associations, or unusual relative proportions of the constituent minerals. That it often does so betray itself in a fashion quite unmistakable, is proved by numerous examples of undoubted mixed rocks which have come under the notice of the present writer.

The question here broached has a very direct application to a subject now much in the minds of petrologists, viz., the endeavor to arrive at some natural (as opposed to a merely Linnæan) classification of igneous rocks. Such a classification must be based, confessedly or implicitly, upon fundamental genetic considerations, and primarily upon the mode of operation of the processes of differentiation in rock-magmas. Rocks resulting from admixture must therefore be excluded from the main scheme and relegated to an appendix. Any discussion which tends to the recognition of this principle and to the establishment of some criterion of distinction will forward the object by disembarrassing the problem of a disturbing element.

ALFRED HARKER.

ON THE HABITAT OF THE EARLY VERTEBRATES

If we take the record as it stands, the appearance of the fishes, the first known vertebrates, is one of the most abrupt and dramatic in the life-history of the earth. They seem to come trooping on the stage of action from some concealed source in full company and clothed in varied and curious armor, and at once a battle scene of prodigious range and duration begins. There had been some feeble premonitions, but these had revealed little of the coming drama. That there had been a long series of preliminary trainings, with trials and changes of armor, and rehearsals, and shiftings of parts, we cannot doubt, but where and how this transpired has been an unsolved mystery, though we have tried industriously to get behind the scenes.

The trivial premonitory signs of the apparition, even when interpreted by retrospective light, only serve to render their meagerness the more singular. If the fishes were armored in the Ordovician period, as the Colorado relics found by Walcott seem to show, and if these mail-clad fishes continued to live in the seas and to develop into the panoplied host that made its apparition during the transition stage from the Silurian to the Devonian, why did they not leave a more fitting registration of their presence? The "imperfection of the geological record" is indeed great, but in seas that preserved soft medusæ and delicate graptolites, it would seem that armored fish should have left abundant and substantial signs of themselves, if they were there. The Trenton relics of Colorado, if taken at their fullest assigned value, help to make such a record, it is true, but at the same time they emphasize its scantiness and nullify the familiar appeal to an unfossilizable softness of structure and perishableness of parts. While they contribute a little to the record, the chief effect of their discovery is to greatly strengthen the opinion long entertained that the fishes must have had a very protracted

pre-Devonian history, and to reënforce the conviction that the evolution of full suites of armor and varied forms of dentition was the work of a prolonged period and had almost necessarily many fossilizable stages previous to the striking display in the Devonian period and this conviction becomes the more firm when it is considered that the differentiation and the armoring extended not only to many different orders, but to subclasses and even classes. If Walcott's interpretations be accepted to relieve the dearth of the record, they must also be accepted as showing susceptibility to fossilization so much the earlier.

As the record now stands, there are fragments of plates, scales, and a supposed notochord from the Trenton of Colorado; but a dearth everywhere else in the widespread and well-studied Ordovician and throughout the early and middle Silurian. Then, in the transitional stages from the Silurian to the Devonian, fish remains appear on both continents, and before the Devonian has passed, they present a rich and varied deployment, embracing not only the two classes *Agnatha* (jawless fishes, *Cyclostomata*) and *Pisces* (true fishes) but all the known subclasses of these and a majority of their orders, according to the most recent authoritative classification.

The physical and biological associations of this extraordinary deployment were peculiar. On neither continent do fish remains appear abundantly in the open sea deposits. They are confined chiefly to the sediments of inland waters or of littoral zones or of embayed arms of the sea. The fish of the Corniferous limestone, perhaps most nearly an exception to this generalization, may properly be put in the last class, for the Corniferous beds were laid down in a great bay with only limited connection with the sea, though the fauna was truly marine.

In the Ludlow "bone bed" of England, where they first make their appearance in abundance, the fish remains are associated with Eurypterids, probably the most gigantic Crustaceans that have ever lived, some of them attaining two meters in length. There is the same association on the continent, notably in the island of Oesel in the Russian Baltic and in Podolia and Galicia,

and so again in the Waterlime group of America in which the *Pteraspis Americana* of Claypole occurs. The physical conditions in all these cases seem to have been peculiar, and in the case of the Waterlime group they were singularly so, for they permitted a host of these large Eurypterids and other Crustaceans to flourish in seeming luxuriance, while only a meager and pauperate marine fauna found an occasional entrance into the series. The conditions seem to have been congenial to the fish and Eurypterids but not to a typical marine fauna.

In the Old Red Sandstone phase of the Devonian both in Europe and America a similar association obtained. A most extraordinary group of fishes and a family of most gigantic Crustaceans flourished where marine life found only an occasional and meager presence. These few marine forms, here and there in a massive deposit, no more imply prevalent salt water than the present marine species in the Bay of San Francisco imply that the gravels, sands and silts of the valley of California and of the Great Basin, which seem to be analogues of the Old Red Sandstone, are prevailingly marine. The further association of the fishes and Eurypterids with land plants and fresh water mollusks, together with a total absence of marine relics from the same beds, leaves no solid ground for hesitating to accept the dominant view of English and other geologists that the typical Old Red Sandstone and its homologues are the deposits of fresh waters and that both the fishes and the Eurypterids found congenial conditions of life in them. As fishes and Eurypterids were found both earlier and later in marine deposits the question arises: *Were the fishes and Eurypterids primarily marine and later became adapted to fresh water, or were they primarily fresh-water forms which were occasionally carried out to sea, and which later became adapted to salt water?* The two cases do not necessarily require an identical answer, but the singular association of the two in unusual display under peculiar conditions and on both continents strongly implies a community of habit, at least at the stages in question. The association is one of the most unique faunal and physical combinations of geologic history.

The earlier occurrence of the Eurypterids in marine deposits is almost as limited as that of the fishes, and yet they were well adapted to fossilization and were actually fossilized as far back as pre-Cambrian times, as Walcott has recently shown by their discovery in the Belt Mountain terrane of Montana. Of about a dozen known genera of Eurypterids, only two or three of those least well known are without associations with formations regarded as fresh water. The relics found in marine sediments may be attributed to transportation from the land just as is done in the case of the terrestrial plants and land insects not infrequently found in marine beds; but transportation in the opposite direction cannot be assigned. In the Ordovician but a single Eurypterid representative is known to occur and of this very little is known. In the pre-Cambrian beds of Montana a more abundant presence seems to be indicated, but little has yet been learned of the concurrent physical conditions. The thousands of Crustacean fragments are associated with a few trails assigned to annelids and some that are possibly molluscan or crustacean, and the inference is that the deposits were made in the sea. From the occurrence of Eurypterids first in marine beds apparently and later in fresh-water deposits it has been inferred that they were originally sea-dwellers and later became adapted to landwaters, but the meagerness of their marine record on the one hand, and their abundance and fine preservation in the fresh-water deposits on the other, give point to the question whether their early marine record is anything more than the chance deposit of river forms borne out to sea. When it is considered that the records of acknowledged marine types are, on the whole, good as such things go, and have been widely and well-studied, there is an incongruity in the case of both the fishes and the Eurypterids between the meager marine records of the Ordovician and Silurian, and the impressive fresh-water record of the same forms in the Old Red Sandstone phase of the Devonian, and this incongruity may well be regarded as significant.

There is reason to believe that opinion has been much influenced — more or less unconsciously no doubt — by general

presumptions, rather than specific ones. There is a strong general presumption, based on theory and observation, that the earliest life was marine and hence that in the gross the course of migration has been from the sea to the land and to the air. But this should weigh nothing in particular cases not in conflict with it, for the descent of reptiles and mammals from the land to the sea is well established, and this in no way contravenes their remote ascension from a marine ancestry. It may be equally true that the fish and the Eurypterids descended from the rivers to the sea in the mid-Paleozoic, though their remote ancestors may have ascended from it.

In dealing with the specific presumptions of the case it is to be noted that the relics of river faunas are imminently liable to be borne down to the sea, while transportation in the opposite direction is unassignable. The presumption is that a land or fresh-water fauna will be somewhat represented in contemporaneous marine sediments if it be readily fossilizable. The fragments of fish and Eurypterids in the marine beds previous to the transition stage at the close of the Silurian are not more than could be expected if fish and Eurypterids were living in the streams of those times, but entirely absent from the seas. Indeed the record is rather scant even on this assumption.

A more or less widely accepted presumption regarding the early states of the land has possibly also weighted against the hypothesis that the fishes had their early development in the land waters, viz., the presumption that the land was without vegetal clothing, and that hence its waters were sterile and unsuited to life. Against this presumption there are several important considerations. If the land were naked, not only would the streams be sterile and silty from the unrestrained wash of the surface, but the waters of the sea border would also be similarly affected in some notable degree. Sea life should have avoided rather than sought the sterile, silty, shore waters. But the abundance of littoral life in the early Paleozoic fails to support this view.

Moreover, if the land were unprotected by vegetation, the rate of transportation of loosened surface materials would probably have been too great to permit complete chemical disintegration. As fast as crystalline grains were separated from their fellow grains by disintegration acting at their contacts, or along cleavage planes, they would doubtless have been promptly carried away to sea and the sands and silts would have been arkose in type. But as far down as the Cambrian at least they are distinctly not so, as a general rule. They are as pronouncedly disintegration-products as in any later age. The Upper Cambrian sandstone of the American interior is a most typical example of a thoroughly disintegrated product. The Huronian series, as developed about the Upper Great Lakes, bears scarcely less distinctive evidence of the dominance of disintegrating agencies than the Mesozoic and Cenozoic terranes on whose origins the influence of an ample clothing of vegetation wrought its full effects.

Still further, the voluminous carbonaceous deposits of the Huronian give support to the assumption that at least lowland vegetation then prevailed in abundance. These carbonaceous deposits have been compared in respect to the amount of carbon with the coal beds of the Carboniferous and Cretaceous periods, and not without some show of justice.

There are good reasons therefore for displacing the presumption, rather current in the earlier half of the century, that the lands of the older Paleozoic periods were barren of vegetation and for the substitution of the presumption that land vegetation was prevalent as far back as the shore deposits display the residuum of complete disintegration and abound in the relics of sea life. Beyond that, where the schists do not radically differ in chemical constitution from the igneous rocks, the era of a naked earth and the reign of disaggregation with slight decomposition may be placed amid the other mysteries of the Basement Complex.

The richness of littoral marine life, at least as early as the Cambrian, the carbonaceous deposits of the Huronian and the

chemical nature of all the Paleozoic and most of the Proterozoic strata, afford, in my judgment, ample ground for the presumption that vegetation clothed the land from a date long anterior to the Paleozoic era and that the land waters were capable of supporting their own appropriate fauna, as well as contributing to the support of that of the sea border.

Now there is one distinctive characteristic of land waters that deserves consideration in the study of the evolution of the early vertebrates, because it was a strenuous dynamic condition constantly impressed upon their fauna. It is their most familiar and essential feature, *their flow.* Neglecting lakes, which are mere incidents, land waters are distinguished by persistent and usually rather rapid motion in a fixed direction, and this is an insistent physical condition to which their fauna must adapt itself. Fortunately this adaptation must take a tangible form, whereas adaptation to the freshness of the water is accomplished by obscure modifications which are not as yet detectable. In flowing water, the animal must maintain its position against the current either by a contact of some resisting kind with the bottom of the stream, or must be provided with an effective mode of propulsion competent to meet the constant force of the current without undue draft on the vital resources; otherwise the animal would be swept out to sea and its race be ended as a stream-dweller. It is different with ocean currents, for they return upon themselves and an animal may yield to them without losing its marine habitat; and besides, they are usually much feebler than river currents.

A glance at the faunas of existing streams, which represent the outcome of ages of trial, shows only three prominent groups of animals that have accomplished the adaptation. The minor instances are negligible. The successful cases are, first and foremost, fish, second, certain mollusks that crawl on the bottom with firm contact, and third, certain crustaceans that are provided with numerous sharp claws that give them ready catch and hold upon the stream bed. The brachiopods that are free in youth, but sessile or pediceled in later life, the cephalopods that are

floating or swimming forms, the corals, the crinoids, the echinoids, and many other sea forms of ancient history and long opportunity, have not made an effective entrance into the streams during geologic time; and this is probably not wholly, and perhaps not chiefly, due to the sweetness of the waters.

A compact form of body presents obvious advantages, except as environment or food or locomotion requires some departure from it, and the vast majority of animals are more or less rotund, and their locomotive devices are adjusted to this form. But the rotund form offers much resistance to rapid currents and unfits the animal for effective stream life unless it persistently hugs the bottom. Neither the rotund floaters and swimmers like the ancient cephalopods, nor the ciliated spawn of the sessile forms are well adapted to resist the unceasing pressure of a rapid stream, and these are practically absent from river faunas.

There is only one conspicuous type that is facilely suited to free life, independent of the bottom, in swift streams, and that is the fish-form. The form and the motion of the typical fish are a close imitation of the form and motion of wisps of water-grass passively shaped and gracefully waved by the pulsations of the current. The rhythmical undulations of the lamprey which perhaps best illustrates the primitive vertebrate form, and is itself archaic in structure, are an almost perfect embodiment in the active voice of the passive undulations of ropes of river confervæ. The movement of the fish is produced by alternate rhythmical contractions of the side muscles, by which the pressure of the fish's body is brought to bear in successive waves against the water of the incurved sections. In the movement of a rope of vegetation in a pulsating current, it is the pressure of the pulses of water against the sides of the rope that give the incurvations. The two phenomena are natural reciprocals in the active and passive voices.

The development in the fish of a rhythmical system of motion responsive to the rhythm impressed upon it by its persistent environment and duly adjusted to it in pulse and force, is a

natural mode of neutralizing the current force and securing stability of position or motion against the current, as desired. Beyond question the form and the movement of the typical fish are admirably adapted to motion in static water and that has been thought a sufficient reason for the evolution of the form, and so possibly it may be, but fishes in static water have not as uniformly retained the attenuated spindle-like form and the extreme lateral flexibility as have those of running water. Among these latter it is rare that any great departure from the typical "lines" and from ample flexibility has taken place, while it is not uncommon in sea fishes. Among the latter not a few have lost both the typical form and the flexibility. The porcupine-fish, the sea-horse, the flounders, and many others are examples of such retrogressive evolution, which is doubtless advantageous to them within their special spheres in quiet waters, but would quite unfit them for life in a swift stream. And if the view be extended to include the low degenerate forms, like the Ascidians, that are by some authors classed as chordates, the statement finds further emphasis.

It is not difficult for the imagination to picture a lowly aggregate of animal cells, still plastic and indeterminate in organization, brought under the influence of a persistent current and caused to develop into determinate organization under its control, and hence to acquire, as its essential features, a spindle-like form, a lateral flexibility, and a set of longitudinal side-muscles adapted to rhythmical contractions, since these are but expressions of conformity and responsiveness to the shape and movement normally impressed by the controlling environment upon plastic bodies immersed in it. The necessity for a stiffened axial tract to resist the longitudinal contractions of the side muscles and thus to prevent shortening without seriously interfering with lateral flexibility, is obvious and is supplied by a notochord. Thus, by hypothesis, the primitive chordate form may be regarded as a specific response to the special environment that dominated the evolution of a previously indeterminate ancestral form.

That some primitive animal aggregate far back in pre-Cambrian time should have found refuge from marine persecution or competition in the sweet running water that entered the sea at so many points, and should have evolved on lines in strict conformity with the dominant force of its new environment does not seem improbable.

If such were the origin of the vertebrate type, its subsequent history and the peculiar phases of fossilization previously discussed are natural sequences.

Distribution from river to river would be slow but inevitable, without the aid of the bizarre agencies of water-fowl, whirlwinds, etc., sometimes appealed to in modern instances. The degradation of the land by streams involves inevitably much piracy, and at the stage of capture the two streams are united for a certain period; and for a still longer period they relieve each other of surplus waters in times of local floods which happen to affect one basin more than the other. Measured by the time requisite for fish migration, these periods of continuous and occasional communication are long. The event itself is, to be sure, infrequent. But in the history of a river basin, the piracy of some one or another of its numerous branches interlocking with the branches of neighboring basins is probably not especially rare. In the next geological period the number of piracies between the headwaters of the Mississippi, the St. Lawrence, the Hudson Bay system, and the Mackenzie will certainly not be few, and before the Cordilleran tract is base-leveled, it may safely be affirmed that piracies at many points will have furnished a migratory tract between the river systems of the interior and those of the Pacific.

Certain attitudes of the sea to the land develop lagoons and sounds behind spits, fringing inlands, and barrier tracts, and if the land be growing at the expense of the sea, the waters of these lagoons and sounds often become wholly cut off from the sea and so pass from the salt to the fresh condition, and thus afford a means of migration from river to river near their mouths. The attitudes which favor this kind of communication occur

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inevitably in the changing relations of land and sea that attend the normal progress of geologic periods. Thus, on the headwaters by piracy and along the sea by lagoons, there are systematic sources of intercommunication by which fresh-water faunas may migrate from basin to basin and may thus occupy quite fully their appropriate domain without dependence upon accidental means or coast-wise communication by temporary entrance of the sea, which may be a resource in some cases. Measured by geologic periods, these means of migration are doubtless sufficiently frequent to be altogether adequate.

The extensions and the changes of domain thus provided to the hypothetical primitive chordate organism may be assumed to have sufficed for its expansion and differentiation through a long period without giving rise to any such degree of overcrowding as to force it to take to the sea for relief; and such intrusions upon the sea as occurred during this initial era may be regarded as individual and accidental.[1] If this be so, it may be inferred that even after the primitive chordates had become differentiated into the ancestral classes, and even into the main ordinal types of the fishes as we now know them paleontologically, and had also attained some measure of induration of parts, the preservation of these parts in the sea sediments would be rare; and this is in accord with experience.

In time, however, the streams must inevitably have become overstocked and a severe struggle for existence must have ensued attended by the acquisition of organs of attack and defense; and at length there must have been an irruption into the sea to avoid the greater enemies and the stronger competition at home. To such an irruption is assigned the remarkable apparition of agnathous and gnathous fishes at the close of the Silurian in varied type and clothed in full armor, expressing the urgency of the competition; though a notable part of the

[1] From early individuals that failed to hold their place in the streams for any reason, and succeeded in maintaining themselves in the sea to which they were carried, there may have sprung the lower chordate types like the ascidians and Balanoglossus, if they really belong to the vertebrate phylum.

apparition, it must be observed, was due to the exceptional preservation of the land record. Thereafter, by interpretation, the habitats of both the Agnatha and the Pisces were more general and varied, a portion taking permanently to the sea, and a portion remaining in the land waters, while a third portion migrated between the two. The well-known habit of many of the last to return to the swift inland streams to initiate each new generation is suggestive of ancestral conditions. The sharks, the hagfishes and many Teleostomes represent divisions that became permanently sea faring. The lung-fishes (Dipnoans), the old-type Crossopterygians, a part of the lampreys, and many others seem to have mainly adhered to the fresh water, at least their present representatives now frequent these waters, either exclusively or in the main. The fossil record of this latter group, throughout the later geologic ages, is well nigh as scant as that previous to the Devonian, and this would seem to be a very significant fact. The lampreys seem to have been ancestrally represented in the Devonian by the little *Palæospondylus gunni* recently found in beautiful preservation in the Achanarras quarry in North Scotland, where conditions for the preservation of fresh-water deposits were exceptionally good. After this single appearance the lamprey type was lost to sight until modern times revealed its probable descendants in the lamprey of our present waters. In like manner, the Dipnoans, after a notable record in the Devonian and Carboniferous periods, where fresh-water life was exceptionally preserved, nearly disappeared from the record, but are now found in three forms, one in each of the three southern continents, Africa, Australia, and South America. So, too, the singular Crossopterygians, though their deployment may have been wider, after a fine display in the Devonian and Carboniferous, passed into a decline in the early Mesozoic and disappeared in the Lias, but are now found in the fresh waters of Africa. Special interest attaches to the Dipnoans and Crossopterygians as the probable ancestors, or the nearest known kin to the ancestors of the amphibians, and through them, of all reptiles, birds, and mammals, because it

carries a certain measure of presumption that the amphibians were fresh-water derivations.

In this larger application of the interpretation herein suggested, the chordate phylum is made to be essentially from first to last a terrestrial race, whose main habitat was the land waters and the land itself, though still a race that sent its offshoots down to sea from time to time from the mid-Paleozoic onwards.

The large hypothetical element in the foregoing interpretation is sufficiently evident and needs neither word of caution nor apology. The problem at present admits of no other than hypothetical treatment. The discussion is merely the attempt of a geologist to interpret from the geologic side the imperfect data that bear obscurely on the habitat of the early vertebrates.

T. C. Chamberlin.

THE BIOGENETIC LAW FROM THE STANDPOINT OF PALEONTOLOGY.

THE interest of the paleontologist in embryology, and in ontogeny in general, lies wholly in the wish to know the origin and relationships of biologic groups; a scientific interpretation of ontogenic data in terms of phylogeny depends on the extent of preservation of the ancestral record in individual development. The broad statement has often been made that each animal gives in its own development an epitome of the history of its race. Because of the law of heredity, this statement would be true, and the record would be complete, if nothing had interfered with the normal course of things. But, in reality, so many secondary elements are introduced in development, that authorities are very much divided as to the value of ontogenic stages as records of race history.

There can be no doubt that students of postembryonic stages have been inclined to claim too much for the law of tachygenesis, while, on the other hand, students of embryology have been inclined to discredit it almost entirely, and to lay little stress on ontogenic stages as a recapitulation of phylogeny. The reason for this disagreement is not far to seek; it lies in the field and in the methods of research of the two groups of morphologists.

Types of development.—Leaving out of consideration the *Protozoa*, which come into being with the essential characteristics of the adults, there are, in the *Metazoa*, two types of development: (1) the *fœtal type*, in which the development takes place in the egg, or in the body of the parent, and the young animal comes into the world in form closely resembling the adult; (2) the *larval type*, in which the young animal comes out at an earlier stage of development, and reaches maturity only after considerable metamorphosis.

Secondary elements will be introduced in either type of development, and those variations that are favorable to the preservation of the species are likely to be perpetuated by heredity. Now in the fœtal type the most favorable variation consists in abbreviation, thus simplifying the development. Any characters that are useful in a free state, but not in a fœtal state, are liable to be lost. Thus in the fœtal type the tendency is toward loss of the record through omission of stages or obscuring them, for many organs that would be highly developed in mature forms, or in free larvæ, will be either suppressed or undifferentiated.

The vertebrates, most of the higher crustaceans, most land and fresh-water mollusks[1] have the fœtal type of development; and these embrace by far the larger part of animals whose ontogeny has been studied. It is not to be wondered at, then, that morphologists who deal exclusively with embryonic stages of these groups should be skeptical about the repetition of family history in individual development. Here many stages are omitted, and the rest so obscured and undifferentiated as to be unintelligible; and secondary characters, due to life in the egg or in the parent, are introduced, effacing what little meaning was left. Then, too, embryologists are often content to trace the animal but a little way toward perfection of development; they study the embryo until the cells begin to divide into groups indicating a beginning of organs, and call this studying ontogeny, when they have stopped before it could be told whether the animal was going to develop into fish, flesh, or fowl. To this sort of study is due the idea of "falsification of the record," a crime of which nature has not yet been guilty, although she at times may not, perhaps, have told the whole truth.

Primary and secondary larvæ.—If the way of the embryologist lies in stony places, that of the student of postembryonic stages is not much smoother; formidable obstacles meet him on every side, reducing his small stock of faith. At the very outset he is confronted by the difficulty that there are two distinct types of

[1] *Dreissensia*, a fresh-water pelecypod, which in very recent geologic time has immigrated from salt water, still goes through its larval development, like its marine relatives.

larvæ: (*a*) *primary larvæ*, such as are more or less modified from ancestral forms, and have continued to develop as free larvæ since the time when they constituted the adult forms; (*b*) *secondary larvæ*, such as have been introduced by cenogenesis into the ontogeny of species that formerly developed by the fœtal process. If ancestral characters have been retained in the egg, then these secondary larvæ may bear some palingenetic characters, and thus be hard to distinguish from primary larvæ; otherwise they will be entirely adaptive, or cenogenetic. A case in point is the development of most insects, whose larval stages are supposed to be largely secondary. Study of individual development in a group of this sort can throw little light on phylogeny.

The student of larval stages must confine himself to the primary sort, if he would correlate them with ancestral genera. The development of the cœlenterates, echinoderms, brachiopods, most mollusks, and the lower crustaceans is direct; thus larval stages of these groups may be bearers, to a greater or less degree, of ancestral characters. But since the free larvæ of even these groups are exposed to natural selection, secondary or cenogenetic characters will be introduced, obscuring the resemblance to ancestral forms; also characters that in the adult ancestral form were functional and fully developed may, in the representative larval stage of the descendant, be so little differentiated as to be unrecognizable.

But how can the morphologist who deals entirely with living species know whether a character is primary, and repeated by palingenesis in the larval history of the descendant, or whether it is secondary, and introduced by cenogenesis into that history? The answer to this lies wholly within the domain of paleontology, for only by finding a stage of growth represented by an ancestral form can the morphologist know that the characters of that stage are ancestral, and not secondary. Larval stages which may be the bearers of ancestral characters must then be compared with the adults of their predecessors, and the paleontologic record must be invoked as a final resort — the court from which there is no appeal.

And this was exactly the method used by Louis Agassiz, who first applied the law of acceleration of development to the study of systematic zoölogy, although it never had much influence on biologic investigation until the palentologic studies of Hyatt in the invertebrates and Cope in the vertebrates placed the law on a sound basis. It was reserved for Alpheus Hyatt to formulate the law and to strengthen theory with practical examples based on study of cephalopods. In his later papers Professor Hyatt[1] has given a more exact and comprehensive definition of the law of acceleration or *tachygenesis:* "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited in successive descendants at earlier and earlier stages according to the law of acceleration, until they either become embryonic or are crowded out of the organization and replaced in the development by characteristics of later origin." A still more definite statement by the same author is the following: "The substages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch, or last embryonic stage."[2]

To insure trustworthy results in verifying this law, the investigator must have groups in which the larvæ are primary and reproduce ancestral characters; in which the living and the fossil are classified on the same basis; of which we have preserved a nearly complete geologic record, and of which material is available for the study of fossil ontogeny as a check on the living. Such groups are especially represented among the *Cœlenterata*, the *Echinodermata*, the *Brachiopoda*, and the *Pelecypoda* and *Cephalopoda* among the mollusks.

Unequal acceleration.— Now, when the morphologist has settled the fact that primary larval stages do actually reproduce, more or less vaguely, characters that existed in the adult forefathers of the generation he is at work on, his troubles are even

[1] Genesis of the Arietidae, p. 9.

[2] Philogeny of an Acquired Characteristic, p. 405.

then not yet ended; for the characters do not necessarily appear in the ontogeny of the descendant in the same association in which they occurred in the ancestor. A character useful to the immature form will have a tendency to be inherited at an earlier age than those useful only to the adult, and so by unequal acceleration of development the parallel between ontogeny and phylogeny is broken. It was once thought that the *Nauplius* larva of the crustaceans was a mature genus, then it was thought to be a larval representative of the extinct radicle of the Crustacea; later still, many morphologists have concluded that the *Nauplius*, while it bears many crustacean characters, still retains too many annelid characters to represent the radicle of the group; it is a typical crustacean larva, but not a representative of the primitive crustacean, and the two sets of characters are thrown together by unequal acceleration. Beecher has shown the same thing in the spiny larvæ of *Acidaspis* and *Arges*, where in the protaspis of these genera the spines characteristic of the adults appear, contrary to usage among the trilobites, in which larval stages are usually smooth. Thus before these animals have assumed characters that would identify them undoubtedly with trilobites they have assumed those most characteristic of their own genera. Jackson has shown that in the larvæ of the *Pectinidæ* unequal acceleration may associate characters that were not synchronous in race history. F. Bernard has recently shown that the prodissoconch of pelecypods is sometimes striated and ribbed, characters that could not have belonged to the primitive pelecypod.

If unequal acceleration causes confusion in the phylembryonic stages, the difficulty is much greater in the larval and adolescent periods, where the shortness of the time of development causes throwing together of characters that were not contemporaneous in the ancestors, and where the small size and general habits prevent differentiation of organs that in the correlative adult forms were highly developed, thus obscuring and even destroying the exactness of the parallelism. Two species of *Placenticeras*, of which the ontogeny has been recently studied

by the writer, must have descended not only from the same perisphinctoid family, but also from the same species of *Hoplites;* and thus, if the parallel were at all exact, they should be alike in the late adolescent stages when they begin to show their generic characters. This, however, is not the case, for they are quite different throughout the cosmoceran stage, and back almost to the end of the larval period, where the transition from goniatite to ammonite took place. If this were interpreted without taking account of unequal acceleration, it would seem that the differentiation of the two species took place back in the Trias, and that different ægoceran forms were the remote ancestors of the two species, which we know could not have been the case.

The writer has recently worked out the ontogeny of two very nearly related species of *Schlœnbachia*, one of which, in its larval period, reproduces very exactly a *Paralegoceras* stage, while the other does not; the latter species has, however, all the paralegoceran characters, but associated with others that this genus never had, but which belonged to later descendants of this genus. There can be here no question of the veracity of nature in keeping the record, the difficulty lies in deciphering it. So it is not to be expected that any one species would give in plain terms the complete phylogeny of a genus, for stages that are plainly differentiated in one will be obscured in another, and only by studying the ontogeny of a number of species of one genus can the morphologist hope to get a complete history. It is still less to be expected that two separate genera, even when closely related, should tell their story in exactly the same terms, for stages that are emphasized in the ontogeny of the one are obscured and possibly even omitted in the other. And in this case the unequal acceleration goes much farther than with closely connected species. In a comparative study of *Lytoceras* and *Phylloceras* the writer[1] has recently shown how rapid this divergence is, and has drawn the conclusion that unequal

[1] The Development of *Lytoceras* and *Phylloceras*. Proc. Calif. Acad. Sci., Third Ser. Geol., Vol. I, No. 4, 1898.

acceleration would account for a large part of the differentiation observed in successive geologic generations.

Retardation.—Another factor that makes it difficult to correlate ontogeny and phylogeny is *retardation* of development. Cope first recognized the principle, but in his writings confused it with unequal acceleration, and since his reasoning was purely theoretical the idea has never gained much foothold in biologic philosophy. Cope's[1] statement of the theory is as follows: "The acceleration in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of inexact parallelism. As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has, no doubt, followed a law the reverse of acceleration, which has been called *retardation*. By the increasing slowness of the growth of the individuals of a genus, and later assumption of the characters of the latter, they would be successively lost." This statement of Cope might apply equally well to unequal acceleration of characters, but in another part of this same work he gives a clearer statement: "Where characters which appear latest in embryonic history are lost, we have simple retardation, that is, the animal in successive generations fails to grow up to the highest point of completion, falling further and further back, thus presenting an increasingly slower growth in the special direction in question."[2]

These remarks of Cope were based on abstract reasoning, but it is possible to bring up some striking cases in support of the theory, notably among the brachiopods. Fischer and Oehlert[3] have shown that while brachiopods go through many metamorphoses in individual evolution, and while each species

[1] Origin of the Fittest, p. 142. [2] Op. cit., p. 13.

[3] Brachiopodes, Mission Scientif du Cap Horn, p. 50–60.

is usually constant in the stages it goes through, it often happens that the individual is arrested in development, never reaching the full generic development of the mature stage. The individual then begins to reproduce its kind before maturity is reached, and tends to give rise to a stock that never reaches the full generic evolution of its ancestors. Dr. C. E. Beecher has well described this: "In each line of progression in the Terebratellidæ the acceleration of the period of reproduction, by influence of environment, threw off genera which did not go through the complete series of metamorphoses, but are otherwise fully adult, and even may show reversional tendencies due to old age; so that nearly every stage passed through by the higher genera has a fixed representative in a lower genus. Moreover, the lower genera are not merely equivalent to, or in exact parallelism with, the early stages of the higher, but they express a permanent type of structure, so far as these genera are concerned, and after reaching maturity do not show a tendency to attain higher phases of development, but thicken the shell and cardinal process, absorb the deltidial plates, and exhibit all the evidences of senility.[1]

If, then, the morphologist tries to study the race history in one of these species thus arrested in development, he cannot read the whole story, for the individual ontogeny will not recapitulate the higher stages lost by retardation.

Another remarkable case is that of the so-called "ceratites" of the Cretaceous. While there have been no goniatites since the Paleozoic, and no ceratites since the Trias, there are found among the ammonites of the Cretaceous some with septa of simple goniatitic character, and others with septa like those of the genuine ceratites. Now since the line of descent is broken, and there is no possibility for a continuous line of these ancient primitive forms to have bridged over the great gap from the Trias to the Upper Cretaceous, we must explain this either by reversion or in some other way. But it is not a simple case of reversion, for, as has been pointed out by several writers,

[1] Amer. Nat., Vol. XXVII, 1893, p. 603.

Douvillé, Nicklès, and others, the septum of adolescent ammonites of this group is not more complex, but really less so, than that of adults, although they are derived from Jurassic genera with complex septa. Thus Douvillé derives the group *Placenticeras-Sphenodiscus* from *Hoplites;* the Pulchellidæ, composed of *Pulchellia*, *Neolobites*, and *Tissotia*, he derives from *Oppelia* of the Jura. Since in each case the ancestral forms are more complex than the descendants, the reduction in complexity of generic evolution can be explained only by retardation or arrested development. F. Bernard has in addition pointed out the fact that the adult of *Pulchellia* is like the adolescent stage of the ancestral *Oppelia*. Now if we define the law of acceleration of development to mean that in a progressive series the young of the descendants correspond to the adults of their more remote ancestors, we find that this does not apply to a retrogressive (retarded) series. In this latter case we must restate the law as follows: the adults of descendants correspond to the young of their more remote ancestors, the higher generic stages to which these ancestors attained having been dropped away by successive retardation or arrested development. The retarded series themselves may become the radicals of new stocks, and so we may have cases where the ontogeny of any one species or genus can never give the full history of the race.

Groups available for correlation.—We see then that the student of morphogeny of animals has to be on his guard, first against the loss of generic stages during the period while the animal is in the egg; then against the introduction of secondary larval stages when the ancestors lacked them; then against the introduction of secondary characters due to adaptation; then against unequal acceleration, bringing together in the ontogeny of the descendant, characters that occurred in separate generations of ancestors; and lastly, against retardation, by which the form never reaches the full generic evolution of its ancestors, and where, if a new series starts out from the retarded form, the complete family history is not recorded in ontogeny.

Is it to be wondered at, then, that the student of morphology becomes a sceptic, or even a rank unbeliever with regard to the value of ontogenic stages as records of history? It is only to be expected that the biologist, especially one that deals almost exclusively with living species, should be inclined to discredit the law of tachygenesis, and to believe that there is such an inextricable muddle of omissions, secondarily introduced characters, and unequal acceleration of those actually repeated, that the record is wholly untrustworthy, or at least illegible. And yet there are so many species and genera in the various groups of invertebrates whose ontogeny is simple, progressive and fairly complete, and whose stages of growth are almost exact repetitions of successive antecedent genera, that it would be impossible to find a student of the morphogeny of the brachiopods, the marine mollusks, or the lower crustaceans, that does not believe implicitly in the value of larval stages of these groups as records of their family history. And this is especially true of the paleobiologists, who regard it of little importance whether the animal under investigation died yesterday, during the flood, or during the Paleozoic era, whether it is preserved in alcohol or in a more permanent museum in the bosom of mother earth; they recognize the fact that the life-history of a Cambrian trilobite has as much bearing on modern biology as does the history of the living crayfish, and that the laws that govern the rise and decline of organisms were just as true then as now.

Not all groups are equally useful to the student of morphogeny, but in each of the lower subkingdoms there are genera of which the ontogeny has been studied and correlated in no uncertain terms with the history of the race. The testimony of these various groups is so uniform, notwithstanding the fact of its having been gathered by men of different beliefs, that its value cannot be doubted. It is also noteworthy that in the higher groups, such as cephalopods and crustaceans, the evidence and the correlations are much more decided.

Cœlenterata.—It has been shown by Dr. C. E. Beecher that the young stages of the Favositidæ correspond to *Aulopora*, or to some other similar unspecialized genus. This same conclusion has been reached by Dr. G. H. Girty based on a study of the ontogeny of *Favosites*, *Syringopora*, and other tabulate corals, all of which are shown to go through an *Aulopora* stage of growth.

Echinodermata.—The only crinoid of which the ontogeny is known is *Antedon*, which has been shown by Sir Wyville Thomson to go through successively stages corresponding to the *Ichthyocrinoidea* of the Paleozoic, and *Pentacrinus* of the Mesozoic, before it becomes free swimming and takes on the characters of *Antedon*.

Dr. R. T. Jackson has been able to prove even in the Paleozoic sea-urchins the possibility of correlating growth stages with phylogeny, in spite of the great difficulties due to resorption of plates, and change of form.

Brachiopoda.—According to Beecher all brachiopods go through a primitive protegulum stage, correlative with the supposed ancestor of the class, although *Paterina*, which was formerly supposed to be this radicle, has been shown to be much more highly specialized than the protegulum stage. The later stages of growth of this class are capable of even more remarkable correlation, as has been shown by Beecher in a number of papers, where every stage of growth is distinctly homologous with well known pre-existing genera; and these same successive genera show a gradual transition in the adults.

Even among the Paleozoic spire-bearers (*Helicopegmata*), this holds good, for Beecher and Schuchert have demonstrated that the early stages of this group are homologous with the terebratuloids (*Ancylobrachia*), aud more especially with the Paleozoic genus *Centronella*, the most primitive of the loop-bearing brachiopods.

Mollusca.—Jackson's correlations of the stages of growth of pelecypods with their race history have already become classic; according to these, every pelecypod begins its bivalve state with

a nuculoid stage, homologous with the primitive radicle of the group. Every *Pecten* goes through stages successively correlative with a nuculoid, *Rhombopteria*, *Pterinopecten* and *Aviculopecten* before it reaches maturity, each stage appearing in the order of the ancestral genus. Even the greatly modified oyster shows its kinship with this group by its nuculoid and *Rhombopteria* stages.

The researches of Branco have made it clear that each group of cephalopods has its typical phylembryo, in a general way correlative with the radicle of the group, and that the later stages may be compared very accurately with ancestral families and genera. The way for this was opened by Hyatt's memoirs on the ontogeny of the ammonites, in which it was shown that in each perfect adult ammonite shell the complete individual ontogeny is recorded. By using this same method Karpinsky has been able to correlate the ontogeny of *Medlicottia* and *Pronorites* with successive ancestral forms, from *Anarcestes*, *Ibergiceras*, *Paraprolecanites*, up to the adult stage.

By the ontogenic method Buckman has been able to get at a sound basis of classification of the Jurassic ammonites, and to correlate the growth stages of many of these with their race history. Although his conclusions as to the systematic position of many of these genera do not agree with the ideas commonly accepted concerning them, it must not be forgotten that these conclusions are based, not merely on ontogenic study alone, but also on the gradual transitions of a series of adults. This is the strongest confirmation that any phylogenic research could ever have.

Crustacea. — Among the most convincing morphogenic researches are Beecher's studies in the ontogeny of the trilobites, all of which are shown to go through a phylembryonic *protaspis* stage, correlative with the primitive crustacean, and similar to the protonauplius of the less specialized living crustaceans. Here, too, it was demonstrated that the larval and adolescent stages of Devonian, Silurian, and even Cambrian trilobites may be correlated with the adults of preëxisting

genera, giving the basis of a natural, or biogenetic, classification of this extinct group.

Many more cases might be added to those cited here, but surely no additional evidence is needed, for all this points in the same direction, whether gathered by believers in or opponents of the theory of evolution. To this latter class belong the evidence brought forward by Barrande in the ontogeny of trilobites, and by Agassiz in the law of recapitulation or acceleration of development. Each of these naturalists used unhesitatingly the method that in the hands of Hyatt and his followers has been so fruitful of results.

JAMES PERRIN SMITH.

THE LOCAL ORIGIN OF GLACIAL DRIFT

NORMAL till is made up predominantly of materials which have not been transported many miles, though some of the minor constituents have often come greater distances. Roughly speaking, the more distant the contributing rock formation, the less its contribution to the till at any given point. There are apparent exceptions to this generalization, but they are chiefly the result either of the unequal exposures of the several formations contributing to the drift, or to their unequal resistance to abrasion.

Locally, the constituents of the drift of distant origin, drop almost to zero. This is true both of drift composed chiefly of clay, and of that which contains abundant coarse material. In extreme cases, stony till is chiefly composed of blocks of rocks that have been moved but little from their original positions. They have been displaced and the clay or sand (the finer portions of the till) have been mixed with them, so that the two sorts of material appear to have been kneaded together. In such cases the rock masses are angular and rough, and frequently increase in size and number from the top of the till to its base. At the base they may be so abundant as to nearly exclude all other constituents. If the surface of the rock be much broken, and its uppermost layers disrupted and crumpled, as is sometimes the case, it may be difficult to say where the line between the bottom of the till and the surface of the underlying rock is to be drawn. Where the rock which gave origin to the drift was not well suited to making bowlders, the comminution of the material gave rise to clayey or earthy matter, as really though less obviously local in origin, as if it had remained in larger pieces. Considering the area of the continental ice-sheets, and the distance which much of the ice traveled, the small proportion of the drift which has come from distant

sources has always seemed a stumbling block to those who are familiar with the facts, but not with their meaning.

In Fig. 1, *a* represents the center of the sector of an ice-cap, and *b d* its circumference. The areas marked 1, 2, 3, and 4 represent successive and equally wide belts of rock of equal resistance and like topography. The center of movement is assumed to be at *a*. When the ice has advanced from *a* to *b d* the deposit of till made at that point is made by ice which, in so far as it has moved from the center, has passed over formations 1 to 4 in succession. In such situations the drift is normally found to contain more material from 4 than from 3, more from 3 than from 2, and more from 2 than from 1.

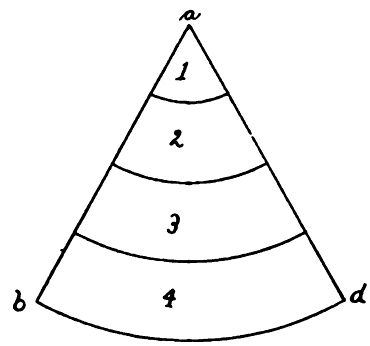


FIG. 1.

It will be understood that if the width of the exposures of the several formations were unequal, or if the several formations were of unequal resistance, the case might be very different. It is also clear that the topography of the several belts will influence the amounts of their contributions, and in view, first, of the varying widths of the various belts of rock passed over by the ice, second, of their varying topographies, and third, of their varying degrees of resistance, many exceptions may arise to the generalization that the contributions of various formations to the till of any locality are in inverse proportion to their distances from the point concerned.

The explanation of the markedly local character of the drift appears to involve several considerations. Fig. 1 illustrates one point involved. Suppose the ice passing over the formations 1, 2, 3, and 4, successively, gathers material with equal facility from each of them. By the time the ice from 1 has spread over 2, the average thickness of the basal layer of drift derived from 1, supposing none of it to have been deposited, would have been reduced to one third its original thickness, since the area of 2 is

three times as great as that of 1. By the time the same ice has spread over 3, the basal layer of drift derived from 1 will have been reduced to one fifth its original thickness, since the area of 3 is five times the area of 1. Still supposing none of it to have been deposited when 4 has been overspread, the thickness of the drift derived from 1 when the ice has covered 4, will be but one seventh of that which it possessed over 1. Even supposing all the drift from 1 to be carried to 4 over the intervening areas, it is thus seen that at such a point as *c*, the amount of distant material should be relatively small. If the ice keeps an equal amount of drift in and beneath itself by gathering enough new material to counterbalance the thinning of that previously held, the till at *c* should be made up as follows:

From formation 1	$\frac{1}{16}$
From formation 2	$\frac{3}{16}$
From formation 3	$\frac{5}{16}$
From formation 4	$\frac{7}{16}$

Thus the spread of the ice will tend constantly to decrease the proportion of basal drift derived from any formation, once that formation is passed.

Since some of the drift derived from 1 would doubtless be lodged as the ice advanced over formation 2, the average thickness of that carried from 1 to 3 will be correspondingly diminished beyond the figure given ($\frac{1}{5}$ of that over 1). Since more of the material from 1 will in all probability be deposited on 3, as the ice advances to 4, the figures given for the thickness on 4 of drift derived from 1 ($\frac{1}{7}$ of that on 1), will need to be still further reduced, and that by a larger amount than that to which the $\frac{1}{5}$ was subject. In view of the continual lodgment of drift, it will be seen that the series of fractions given above, namely $\frac{1}{16}$, $\frac{3}{16}$, $\frac{5}{16}$, and $\frac{7}{16}$, will need to be changed by some undetermined amount, but so that the extremes will be farther apart, and the differences between successive members greater. If $\frac{1}{4}$ of the drift carried from 1 were deposited on 2, 3 and 4 and $\frac{1}{3}$ of that from 2 on 3 and 4, and $\frac{1}{2}$ of that from 3 on 4, the last member of the preceding series of fractions would be increased at the

expense of others. The preceding series would then be brought to some such terms as the following:

From formation 1 - - - - - -	$\frac{1}{64} = 1\frac{1}{2}\% +$
From formation 2 - - - - -	$\frac{4}{64} = 6\% +$
From formation 3 - - - - - -	$\frac{15}{64} = 23\% +$
From formation 4 - - - - -	$\frac{44}{64} = 69\% +$

Thus the constant tendency of the drift to lodge, after being once started, tends still further to diminish the quantity of drift from any formation after the formation is passed.

The effectiveness of the tendency to lodgment of drift near its source is dependent on several conditions. One of them is the rate and steadiness of movement, and another the topography of the surface. The edge of the ice is not believed to have moved forward at equal rates, either during its advance or during its retreat. Whenever the edge of the ice, after a given advance, remained approximately constant in position for a period of years, all the drift brought to the edge of the ice during the halt accumulates beneath it. It presently accumulates in sufficient quantity to form a submarginal ridge or barrier, and when the ice is again affected by movement sufficient to carry its edge farther forward, it is obliged to override or carry forward this submarginal accumulation. Judging from the phenomena of North Greenland, such material was more largely overriden than urged along. Thus the drift gathered toward the center of the ice field is lodged in exceptional quantity wherever the edge of the ice was for a time nearly stationary, and the ice which passed on over the drift which was lodged proceeded to gather a new load made up chiefly of material derived from the surface outside the position of the preceding halt. This tends to emphasize the local facies of the drift.

These considerations in themselves would be quite sufficient, as the last set of fractions shows, to explain the great predominance of relatively local material in the drift of any given region, but other factors serve to emphasize the point still further.

The top of the ice-sheet moves forward faster than the bottom. One reason for this is that the lower part, which is more

fully charged with débris, becomes more rigid, while the more mobile part above moves on over it. If in Fig. 2 the several curves *a*, *b*, *c*, *d* represent the profiles of the ice in successive stages of advance, the ice which is at the bottom, and which is eroding formation 4, may not be the ice which was at the bottom over 2, but instead ice which was well up from the bottom over this formation. In this case it is clear that the ice working on 4 has relatively little material derived from 2. At first thought it might seem that it should have nothing, but this conclusion does not follow. As the relatively débris-free ice above moves

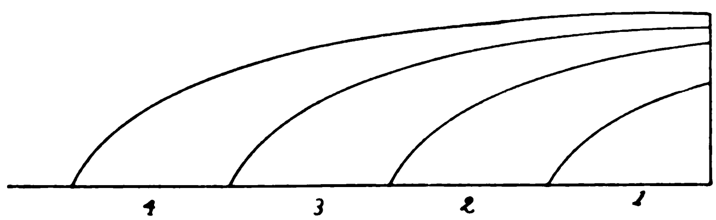


FIG. 2.

over the relatively heavily débris-charged ice below, it drags along some of the material lying in the upper part of the débris zone. Thus as the ice moves over 4, the upper part, being in faster motion, will be carrying along some of that derived from 2 and and even from 1, so that at least a small amount of the material from these formations is to be expected in the bottom of the ice over 4. Nevertheless, the tendency is all along to leave the material already carried by the ice in the rear, and to let the advancing edge acquire its own load, primarily from the successive formations invaded. The result of differential movement, the faster movement being above, is to diminish still further the proportion of the material in the drift at any given point which was derived from distant sources. Because of the effects of differential movement therefore, the last series of fractions would need to be still further changed, so that the first member would be smaller and the last larger.

The topography over which the ice had moved would also influence the proportions of material of near and distant origin.

If the ice passing over 2 encounters a rough topography, so that drift was introduced into the ice far above its base, a large amount of matter from 2 would go forward in the more rapidly moving upper part, and be found in the ice, and finally in the drift, over 4, or beyond.

There is at least one other factor involved. Much of the ice which passes over 4 (Fig. 2) never passed over 1, but accumulated on 2, 3, and 4. This does not preclude the passage of some ice from 1 to 4, but simply means that much of the ice at 4 has never had a chance to work on 1. The idea involved may be gathered from Fig. 3. Let the lines *a*, *b*, and

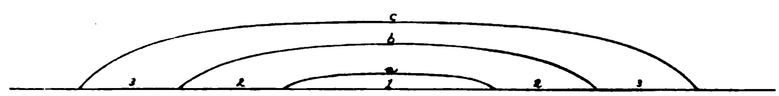


FIG. 3.

c, respectively, represent the successive profiles of a growing ice-sheet. Much of the upper part of the ice, the profile, of which is *c*, accumulated over areas 2 and 3 and did not come from 1, as already stated. This upper ice which never worked on 1, is moving more rapidly than the ice at lower levels which came in part from 1. Furthermore the conditions of snowfall and movement are such as to develop a high marginal and a low central gradient. The excessive marginal snowfall, for such was probably the condition, will in some sense check movement from the center, and make the marginal portion of the field the effective dynamic center of movement. The origin of much of the ice far from the center of the ice-sheet, where it had no chance to work on rock formations near the center, tended still further to make the material carried and deposited by the ice at any point of local origin. The effect of this factor is to still further differentiate the fractions of the preceding series.

When the spread of the ice, the constant tendency to lodgment of drift in transit, the differential movement, and the marginal origin of much of the ice are all considered, it is probably true that the fractions given on pp. 428, 429 give much

too large a percentage of widely transported material in the drift occupying such a position as that to which the fractions are applied. Taken together, too, these factors would seem to explain adequately the local character of the material of the till.

R. D. S.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.

(*Continued from p. 425, Vol. VII.*)

WALCOTT[1] discusses pre-Cambrian fossiliferous formations of North America. In two cases only have fossils of undoubted organic origin been shown to occur in formations of reasonably certain pre-Cambrian age, namely, the Grand Canyon of Arizona, and the Belt terrane of Montana. The Etcheminian terrane of New Brunswick and Newfoundland is doubtfully a third instance.

A brief account is given of the stratigraphy of each of the areas of pre-Cambrian sedimentary rocks. No new points appear except in the description of the Belt terrane of Montana; the account of the Belt terrane is therefore the only one summarized with reference to stratigraphy.

The Belt terrane of Montana covers an area of more than 6000 square miles in central Montana. The principal beds of the terrane are as follows:

Marsh shales	300 feet.
Helena limestone	2,400 "
Empire shales	600 "
Spokane shales	1,500 "
Greyson shales	3,000 "
Newland limestone	2,000 "
Chamberlin shales	1,500 "
Neihart quartzite and sandstone	700 "
	12,000 feet.

Throughout the area the Belt terrane is overlain unconformably by middle Cambrian rocks (Flathead). The Cambrian rocks rest on various members of the Belt series, and in places the Belt terrane is entirely wanting, the Cambrian resting directly on the Archean schists. In such cases, moreover, the character of the Belt beds indicates that the Cambrian overlaps the Belt series. The base of the Cambrian is not markedly conglomeratic. At most of the outcrops where the lower

[1] Pre-Cambrian Fossiliferous Formations, by CHARLES D. WALCOTT: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199–244.

beds of the Flathead (Cambrian) sandstone come in contact with the Belt rocks the dip and strike of the two are usually conformable, so far as can be determined by measurement. This holds good all around the great Belt Mountain uplift. It is only when contacts are examined in detail, as near Helena, that the minor unconformities are discovered, and only when comparisons are made between sections at some distance from one another that the extent of the unconformity becomes apparent. In general from 3000 to 4000 feet of the upper strata of the Belt terrane were removed by erosion in late Algonkian time before the Middle Cambrian was deposited. It is believed that an unconformity of this extent is sufficient to explain the absence of Lower Cambrian rocks and fossils and to warrant the placing of the Belt terrane in the Algonkian system.

The fossils thus far found in the Belt terrane occur in the Greyson shales at a horizon approximately 7700 feet beneath the summit of the Belt terrane at its maximum development. The fauna includes four species of annelid trails and a variety that appears to have been made by a minute mollusk or crustacean. There also occur in the same shales thousands of fragments of one or more genera of crustaceans.

Grand Canyon series. — The fossils of the Grand Canyon Upper Cambrian series consist of specimens of a small discinoid shell found in the upper division of the Chuar terrane, and a Stromatopora-like form from the upper portion of the lower division and the central portion of the upper division of the Chuar. Other obscure forms appear whose identification is doubtful.

In New Brunswick certain rocks below the middle Cambrian, according to Matthew, contain fossils which may be pre-Cambrian. (See summary of Matthew's articles, following, p. 435, and of later article by Walcott, p. 436.)

The Llano series of Texas is a series of alternating sandy shales, sandstone, and limestone, very similar to those of the Grand Canyon pre-Cambrian series and overlain by a middle Cambrian sandstone similar to the Tonto sandstone of the Grand Canyon district. No fossils have been found in these rocks, although no systematic search has been made.

The Avalon series of Newfoundland includes all the pre-Cambrian sedimentary rocks of that area. Overlying them are Cambrian strata carrying olenellus fauna.

The Aspidella of the Momable slates is probably of organic origin, but it may be questioned. Other reported forms are inaccessible for study.

In the Lake Superior country markings have been reported as found in the Huronian iron formation of the Menominee iron district of Michigan. An examination of the specimens indicates that they probably are from the basal detrital material of the Cambrian which rests upon the Huronian iron formation. In the Animikie rocks of the Lake Superior region the evidence of life consists of the presence of graphitic material in the slates and of a supposed fossil mentioned by Mr. G. F. Matthew. In the Minnesota quartzite of the Upper Huronian series lingula-like forms and an obscure trilobitic-looking impression are described by Winchell. The latter has been examined and the conclusion is reached that it is of inorganic origin. As to the lingula forms, the weight of evidence is in favor of their being small flattened concretions.

In general, the reported discoveries of fossils in the crystalline rocks of the Algonkian are as yet too problematic to be of value to the geologist and paleontologist. Apparently the best that can be said of Eozoon and allied forms is that they may be of organic origin, but it is not yet proved. The same appears to be true of the supposed fossil sponges described by Mr. G. F. Matthew from the Laurentian rocks of New Brunswick. The graphite in pre-Cambrian forms is probably in many cases of organic origin, but of the character of the life we know nothing.

Palaeotrochis formerly referred to as a pre-Paleozoic coral is determined by Professor J. A. Holmes and J. S. Diller as of inorganic origin.

Matthew[1] describes a Paleozoic terrane beneath the Cambrian in St. Johns and Kings counties, New Brunswick, on Cape Breton, and near Smith Sound, Newfoundland. This terrane is unconformably below Cambrian strata bearing paradoxides and protolenus fauna, and is given the name *Etcheminian*. The faunal features as distinguished

[1] A Paleozoic Terrane Beneath the Cambrian: Annals N. Y. Acad. Sci., Vol. XII, No. 2, 1899, pp. 41–56.

Preliminary Notice of the Etcheminian Fauna of Newfoundland: Bull. Nat. Hist. Soc., New Brunswick, XVIII, Vol. IV, 1899, pp. 189–197.

Preliminary Notice of the Etcheminian Fauna of Cape Breton: Bull. Nat. Hist. Soc., New Brunswick, XVIII, Vol. IV, 1899, pp. 198–208.

The Etcheminian Fauna of Smith Sound, Newfoundland: Trans. Roy. Soc. of Canada, 2d ser., 1899, Vol. V, sec. 4, pp. 97–119.

from the Cambrian are the great preponderance of tube worms, absence or rarity of trilobites, minuteness of the gasteropods, except Patellidae, minuteness of the brachiopods, and the minuteness of the crustaceans.

Walcott[1] believes the *Etcheminian* terrane of New Brunswick and Newfoundland called pre-Cambrian by Matthew to be of Lower Cambrian age. His evidence is:

1. That the Olenellus fauna in Newfoundland occurs 420 feet beneath the Paradoxides fauna, in the heart of the Lower Cambrian "Etcheminian."

2. That fragments of the fauna are found 460–480 feet below the Protolenus fauna in the "Etcheminian" of the Hanford Brook section of New Brunswick.

3. That in the undisturbed, unbroken Highland Range section of Nevada the Olenellus fauna is 4450 feet below the Upper Cambrian fauna, and that the Olenoides (Dorypyge fauna of Matthew) is 3000 feet below the horizon of the Upper Cambrian fauna and 1450 feet above the horizon of the *Olenellus gilberti* fauna.

4. That in the southern Appalachians the Olenellus fauna occurs more than 7000 feet below the highest Cambrian fauna known in that region, and fully 2000 feet below a typical Olenoides fauna.

Matthew[2] makes rejoinder to Mr. Walcott's discussion of the age of the Etcheminian terrane. He argues that Mr. Walcott depends chiefly upon the presence of Coleoloides typicalis as showing the presence of the Olenellus fauna; that this form is not always distinguishable from Hyolithellus micans, a problematical fossil probably of the tube worms, which, with the brachiopods, is the most striking of the fossils of the lower (Etcheminian) terrane. Moreover, the particular form of Olenellus which Mr. Walcott has found is the Olenellus bröggeri, rather than the Olenellus thompsoni, the original Olenellus. Olenellus thompsoni is supposed to occur above the Olenellus bröggeri, yet the Protolenus and Paradoxides faunas follow in regular succession to the fauna of the Olenellus bröggeri. The question is asked: Where is the fauna of Olenellus thompsoni? Its absence is supposedly taken as evidence of the presence of the unconformity held by Matthew.

[1] Lower Cambrian Terrane in the Atlantic Province, by C. D. WALCOTT: Proc. Washington Acad. Sci., Vol. I, 1899, pp. 301–339.

[2] Mr. Walcott's View of the Etcheminian, by G. F. MATTHEW: Am. Geol., Vol. XXV, 1900, pp. 255–258.

Emerson[1] describes the Algonkian rocks occurring in the southwestern corner of the Holyoke quadrangle in Massachusetts and in the area to the west. These are gneisses and limestones making up a series called the Washington gneiss. They are of sedimentary origin with the possible exception of the hornblende-gneiss of East Lee.

In general in western Massachusetts the Washington gneiss appears in oval areas surrounded by younger strata, the line of these ovals extending south from the Hoosac Tunnel along the crest of the Green Mountain plateau. The gneiss enters the Holyoke quadrangle at the southwest corner and runs up across the town of Tolland, narrowing to a point near Black Pond.

Woodworth[2] describes the Algonkian rocks in the lower portion of the Blackstone Valley and west of Providence, R. I., near the western margin of the Narragansett basin. From the typical development of the Algonkian rocks along the Blackstone River between Woonsocket and Pautucket, they are called the Blackstone series. This series is divided into the Cumberland quartzites; the Ashton schists, representing the finer sediments succeeding the deposition and partial erosion of the Cumberland quartzites, and in part probably igneous in origin; and the Smithfield limestone, apparently of sedimentary origin. As yet no facts have been discovered to show whether the limestones are of the same age or newer than the Ashton schists. The rocks of the Blackstone series are separated and penetrated by granitic intrusions or batholites.

The Blackstone series is assigned to the Algonkian because of the difference in metamorphism of the Blackstone series and Lower Cambrian strata, bearing Olenellus fauna, in North Attleboro. The Cambrian strata are little altered and lie in close proximity to the granite. Four miles west the Blackstone series is infolded with a similar granite and much altered.

Kemp[3] gives a petrographical account of the granites of the

[1] B. K. EMERSON: Geology of Old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties: Mon. U. S. Geol. Surv., No. 29, 1898, pp. 19–30. With geological map. This covers the area of the Holyoke quadrangle and in addition a narrow area to the north and east.

Holyoke folio, Massachusetts-Connecticut: Geol. Atlas of the U. S., No. 50, 1898.

[2] Geology of the Narragansett Basin, Part 2, by J. B. WOODWORTH: Mon. U. S. Geol. Surv., No. 33, 1899, pp. 104–118. With geological map.

[3] Granites of Southern Rhode Island and Connecticut, with Observations on Atlantic Coast Granites in General, by J. F. KEMP: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 361–382; with plates.

Atlantic coast of pre-Cambrian and later age. He finds a striking predominance of biotite granites and gneisses.

Kemp,[1] in connection with a description of the magnetite deposits of the Adirondacks of New York, publishes a geological map of portions of Elizabethtown and Westport townships in Essex county, showing the distribution of the pre-Cambrian magnetite-bearing gabbros, the gneisses, and the limestones. No point in addition to those given in previous reports appears.

Merrill[2] gives a brief summary account of the geological formations of New York, including the pre-Cambrian of the Adirondack area and of the southeastern part of the state. Accompanying the report is a relief map showing the outlines of the geological formations.

Cushing[3] describes an augite-syenite-gneiss near Loon Lake in the Adirondacks. It is nearly related to the anorthosites in age, inasmuch as it is intrusive in the Grenville series, but it is much older than the pre-Potsdam diabases of the region. A study of the relations of the syenites and anorthosites indicates that the syenites are in part a result of differentiation in the anorthosite magma after reaching its place of final cooling, and in part are somewhat later in date.[4]

Smyth[5] summarizes his ideas to date on the geology of the Adirondacks. Gneisses, limestone, and gabbro are the principal rocks. From studies in the western Adirondacks it is certain that some of the gneisses are of igneous origin, being granites syenites, gabbros, etc., which have been modified by metamorphism; while others, with equal certainty, are altered sediments. But by far the larger part of the gneisses have as yet received no careful study. The limestones are certainly sedimentary. Their relations to the gneisses are in doubt, but some parts of the gneisses are certainly younger than the limestones,

[1] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP: Nineteenth Ann. Rept. U. S. Geol. Surv., 1897–8, Part 3, 1899, pp. 377–422. With geological map.

[2] A Guide to the Study of the Collections of the New York State Museum, by F. J. H. MERRILL: Bull. N. Y. State Museum, Vol. IV, No. 19, 1898, pp. 109–262; with geological map.

[3] Augite-Syenite-Gneiss near Loon Lake, New York, by H. P. CUSHING: Bull. Geol. Soc. of Am., Vol. X, 1899, pp. 177–192.

[4] The anorthosites are a part of the great gabbro mass which forms the core of the Adirondacks intruding pre-Cambrian sedimentary and igneous gneisses.

[5] Geology of the Adirondack Region, by C. H. SMYTH, JR.: Appalachia, Vol. IX, No. 1, May 1899.

and this may be true of all. The gabbro breaks through both gneisses and limestones. It presents two phases, an anorthosite, and a gabbro containing abundant pyroxene and other ferro-magnesian minerals. In places also in the western Adirondacks the granites and syenites break through the limestone.

Barlow[1] gives a further account of the results of work being carried on by himself and Dr. Adams in the counties of Hastings, Haliburton, and Renfrew, Province of Ontario. Many of the so-called conglomerates of the Hastings and Grenville series are believed to be autoclastic rocks or pseudoconglomerates which have resulted in the main from complex folding and stretching. Therefore such rocks cannot be cited as evidence of the clastic origin of the Hastings and Grenville series, as has been done.

Barlow[2] describes the geology of the Nipissing-Temiscaming map-sheets, comprising portions of the district of Nipissing, Ontario, and the county of Pontiac, Quebec.

Laurentian and Huronian rocks occupy most of the area. These do not include a few small isolated inliers of crystalline limestone and gneissic rocks which resemble the Grenville rocks to the south and southwest. These are so small in quantity that they are not mapped. Their relations to the Huronian are not discussed.

The Laurentian rocks occupy the two thirds of the area of the two sheets. While probably representing in part the first formed crust of the earth, and therefore the basement upon which the Huronian rocks were laid down, the Laurentian has undergone successive fusions and recementations before reaching its present condition. It is now a complex of plutonic rocks which in general show irruptive relations to the overlying Huronian series. However, on Lake Temiscaming the Laurentian is unconformably below, and in direct contact with, an arkose of Huronian age, which has apparently been derived from the disintegration the Laurentian granite.

The Huronian occupies about a third of the combined area of the two sheets. It is separable into three divisions, in ascending order as

[1] On the Origin of some Archean Conglomerates, by A. E. BARLOW: The Ottawa Naturalist, Vol. XII, 1899, pp. 205–217. See Am. Journ. Sci., 4th series, Vol. III, 1897, pp. 173–180.

[2] Geology and Natural Resources of the Area included by the Nipissing-Temiscaming Map-sheets, comprising Portions of the District of Nipissing, Ontario, and of the County of Pontiac, Quebec, by A. E. Barlow: Ann. Report Geol. Surv. of Canada, Vol. X, Pt. 1, 1899, pp. 302. With geological map.

follows: (1) breccia or breccia-conglomerate, (2) graywacke shale or slate, and (3) feldspathic sandstone or quartzite. The maximum thickness of the first division is 600 feet; of the second, 100 feet; and of the third, 1100 feet. Associated with these clastic rocks are various rocks of igneous origin, including deep-seated diabase and gabbro and volcanic ejectamenta.

Comments.—The nature of the relations of the Huronian and Laurentian rocks has so long been a subject of controversy and the ground has been gone over so many times that comment seems unnecessary. But for readers who have not followed the controversy a statement of one of the main points of contention may be of service. The Laurentian rocks of Barlow and other Canadian geologists form the basement upon which the Huronian rocks were deposited, and they also have intrusive relations to the Huronian rocks. This anomaly is explained by the fact that the granites and gneisses really form the basement upon which the Huronian rocks were deposited, but that since this deposition the granites and gneisses have been softened by fusion, perhaps due to the weight of the overlying rocks, and that they now invade the lower portions of the Huronian rocks.

Other geologists, particularly the United States geologists, have maintained that no evidence has been adduced to show that there has been any softening of the basement granites near their contact with the overlying Huronian sediments; that the granites and gneisses included under the Laurentian by the Canadian geologists are of widely different ages; that they comprise both the original basement rocks, in their original form, upon which the Huronian was deposited, and later rocks, intrusive into both the Laurentian and Huronian; and furthermore, that in most regions it will be possible by close areal mapping to distinguish these different granites and gneisses. They would map the basement granites and gneisses as one series, and separate from them all later intrusives.

Although Mr. Barlow has for many years maintained the total absence of the normal erosion unconformity between the Laurentian granite and the Huronian, he now reports the "discovery" of such a contact near Lake Temiscaming. In finding a normal erosion unconformity in this area he is many years behind Pumpelly, Irving, and Van Hise, as indicated in a comment on a previous article of Mr. Barlow.[1] It is thus now agreed that the original basement granites and

[1] JOUR. GEOL., Vol. II, p. 419.

gneisses are present in this area. Mr. Barlow cites no evidence to show that softening of the granites and gneisses has anywhere occurred immediately subjacent to the sediments, resulting in the invasion of the sediments by the granites and gneisses; that any eruptive relations now found are not those of the normal intrusion of granite magmas into both the original basement and the overlying sediments.

Ells[1] gives an historical account of the geological nomenclature of that part of Canada which extends roughly from the Red River of Manitoba eastward over Canada. The present usage with reference to pre-Cambrian rocks may only be mentioned.

In Nova Scotia the term pre-Cambrian has been given to certain old crystalline rocks which were found to underlie the recognized Cambrian of the coast or of the gold-series, and which were found to strongly resemble certain portions of the Laurentian or Huronian of the western provinces.

In New Brunswick there has been little change in the nomenclature proposed by Matthew, Bailey, and Hunt. The lowest division of the crystalline rocks was held to conform most closely in its details to the Laurentian of the Canadian Survey. This series was divided into a lower and an upper division, the former of which was regarded as the equivalent of the Lower or Fundamental Gneiss of the Ottawa district, while the latter was supposed to represent the limestone and gneiss of the Grenville series of Quebec. The Huronian was made to include three divisions, viz., the Colebrook, the Kingston, and the Coastal. Since this time Matthew has introduced the term Etcheminian to designate certain fossiliferous sediments found beneath the middle Cambrian, probably belonging to the more recent portion of the pre-Cambrian formations.

In Ontario and Quebec the oldest granite-gneiss may be styled Laurentian. The second member of the scale, or the Huronian, may be made to include, as its lowest portion, that part of the crystalline series, once regarded also as part of the Laurentian system, and known locally under the names Grenville and Hastings series, the relations of which to the Laurentian proper are apparently of two kinds, either a stratigraphical sequence, with a probable unconformity, owing to their difference in origin; or a contact of intrusion; and that portions of the Grenville and Hastings series correspond, while the latter is carried

[1] Canadian Geological Nomenclature, by R. W. ELLS: Trans. Royal Soc. of Canada, 2d series, Vol. V, sec. IV, 1899, pp. 3–38.

upward through less altered sediments to the upper members of the Huronian system.

In the Lake Superior region the Huronian is succeeded upward by the rocks of the Cambrian, represented by the Upper Copper-bearing series, or the Animikie and Nipigon groups; while in eastern Ontario this portion of the scale is apparently entirely lacking, the formation succeeding the crystalline series being the Potsdam sandstone, which is now held to represent the lowest number of the Cambro-Silurian or Ordovician system.

Comment.— Adequate discussion of the above scheme of nomenclature is quite impossible in the space available. It may be said only that the scheme will be dissented from on many important points by many of the United States geologists.

Crosby[1] describes the Archean-Cambrian contact near Manitou, Col. A sandstone of Cambrian age rests upon an Archean granite complex. The granite floor has very small erosion inequalities. These inequalities are hummocks, not hollows; erosion remnants, and not channels; clearly marking the end, and not the beginning of a process of base-leveling.

It is believed that such an even contact plane between the Cambrian and pre-Cambrian series is widespread and characteristic in North America. It appears to be the case in the valley of the Eagle River and in the canyon of the Grand River above Glenwood, Col.; in the Black Hills of South Dakota, examined by the writer; in the Grand Canyon of the Colorado, described by Walcott; and in Wisconsin, described by Irving.

In the Manitou, Eagle River, and Black Hills areas, throughout the Rocky Mountains, and eastward to Champlain Valley and beyond, the Cambrian has a non-arkose character; it has been thoroughly sorted and washed by water, a fact which indicates that the incursion of the sea was an extremely slow one. It is believed that the plane surface of the Archean has resulted from the incursion of the sea due to the subsidence of the land, and not from the action of subaerial agents, for in the latter case only an approximate plane could have resulted because of differential erosion.

Emmons[2] describes the Archean rocks of the Ten-mile quadrangle of Colorado. These rocks outcrop to the east of the great fault — the

[1] Archean-Cambrian Contact near Manitou, Col., by W. O. CROSBY: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 141–164.

[2] Ten-mile District Special Folio, Colorado, by S. F. EMMONS: Geol. Atlas of the U. S., No. 48, 1898.

Mosquito fault — running north of Leadville. They consist of granites, granite-gneisses, mica-schists, and amphibolites, with pegmatite veins traversing them in every direction. Gneisses and schists are the prevailing types.

A small patch of Cambrian sediment is found resting unconformably on the Archean to the east of the Mosquito fault.

Hague[1] describes the Archean rocks of the area covered by the Absaroka folio in the northwestern part of the state of Wyoming. These consist of crystalline-schists and gneisses, mainly mica-gneiss, amphibolites, and schists distinctly light colored, which are found only in the northeastern part of the Crandall quadrangle.

Sedimentary rocks of middle Cambrian age overlie the Archean rocks unconformably.

Irving[2] gives a detailed description of the geology of an area in the northern Black Hills of South Dakota. The Algonkian rocks consist of quartzites, slates, phyllites, and schists, all of sedimentary origin. No new point is added concerning the stratigraphy of the pre-Cambrian rocks.

C. K. LEITH.

[1] Absaroka Folio, Wyoming, by ARNOLD HAGUE: Geol. Atlas of the U. S., No. 52, 1899.

[2] A Contribution to the Geology of the Northern Black Hills, by JOHN DUER IRVING: Annals N. Y. Acad. Sci., Vol. XII, 1899, Pt. 9, pp. 187–340.

STUDIES FOR STUDENTS

THE EOCENE OF NORTH AMERICA WEST OF THE 100TH MERIDIAN (GREENWICH).[1]

CONTENTS.

[1] The following essay is the outcome of a topical study undertaken by the writer as a student at the University of Chicago. While it is based entirely on the literature of the subject, it brings together so many scattered data concerning a series of formations which often seem intangible to the student, that it is printed in the belief that the summation may be serviceable to students who wish to get information beyond that of text-books, and who have not access to the original reports.—[ED.]

THE Eocene deposits of western North America may be divided into three groups, namely, those laid down in fresh water, those laid down in brackish water, and those laid down in sea water. To these should probably be added those deposited by streams, though this class of formation has not been generally differentiated from the first.

1. *The fresh-water deposits* stretch with many interruptions from New Mexico and Colorado northward and nothwestward through Utah, Wyoming, Montana, North Dakota, the Dominion of Canada, to the Arctic Circle and probably the Arctic Ocean. The formations belonging to this area are the Fort Union, which is the Upper Laramie of the Canadian Geological Survey, the Kenai, Puerco, Torrejon, Wasatch, Bridger, including Green River, Uinta, Huerfano, Mojave, Amyzon, and Manti. In addition there are non-fossiliferous conglomerates which are supposed to be of Eocene age, as follows: Sphinx conglomerate, Pinyon conglomerate, and San Miguel conglomerate.

2. *The brackish-water deposits* extend with interruptions from Oregon through Washington into British Columbia. The formations belonging to this group are Arago and Puget.

3. *The marine deposits* in Oregon and California. The formations belonging to this group are Tyee, Umpqua, Martinez, and Tejon.

In the following pages the known data concerning the distribution and nature of these several formations is summarized, and their correlation as determined by various investigators indicated.

THE FRESH-WATER BEDS.

THE FORT UNION FORMATION.

The Fort Union beds are named from a former military fort on the Missouri River in North Dakota where they are typically exposed. They occur in North Dakota, Montana, extending thence north and northwest into Canada and with interruptions to the Arctic Circle and probably to the Arctic Sea. These beds are thus described by Meek and Hayden[1]: "Beds of clay

[1] Quoted by Clark, U. S. Geol. Surv., Bull. 83, p. 113, 1891.

and sand with round ferruginous concretions and numerous beds, seams, and local deposits of lignite; great numbers of dicotyledonous leaves, stems, etc." Under the name *Paskapoo*, Tyrrell describes this formation as being at least 5700 feet in thickness[1]: "The beds consist of more or less hard, light gray or yellowish-brownish weathering sandstone, usually thick-bedded, but often showing false bedding; also of light bluish-gray and olive sandy shales, often interstratified with bands of hard lamellar ferruginous sandstone, and sometimes with bands of concretionary blue limestone, which burns into an excellent lime. The sandstones consist of very irregular, though slightly rounded, grains of quartz, felspar, and mica, cemented together in a calcareo-argillaceous matrix."[2] Its fauna shows that this entire series is of fresh-water origin.

Because of the nature of the stratigraphy of the rocks of this region, and because of the fact that dinosaurs became extinct immediately before the Paskapoo epoch, because a time of great disturbance "in which the Rocky Mountains were uplifted" preceded the Paskapoo, Tyrrell thinks this break between the Cretaceous and Paskapoo marks the close of the Cretaceous, "and that the Tertiary epoch began with the commencement of the Paskapoo period, during which a great thickness of sandstones and sandy shales was laid down without any apparent break or unconformity. In this Paskapoo series, then, we have the representative of the Eocene of Europe."[3]

Weed, writing of the Crazy Mountains of Montana, says[4]: "These mountains are formed of Livingston beds, conformably overlain by a series of sandstones and clay shales, characterized by fresh-water fauna, and lithologically distinct and readily differentiated from the somber-colored sandstones of volcanic material composing the Livingston beds. The plant remains of these [upper] beds are not of Laramie nor of Denver bed types, but are species characteristic of the strata in the vicinity of Fort

[1] Geol. and Nat. Hist. Surv. of Canada, Ann. Rep. n. s., Vol. II, p. 135 E. 1886.

[2] TYRRELL: loc. cit., p. 136. [3] Loc. cit., p. 138.

[4] Amer. Geol., Vol. XVIII, pp. 204, 205, 1896.

Union, and that name is therefore adopted for the formation." A section is given showing Fort Union beds to be 4648 feet thick at this place. "The importance of this section, which is the only one known to the writer in which the Fox Hills, Laramie, Livingston, and Fort Union formations occur superimposed, is apparent when it is considered that in eastern Montana and Canada the Fort Union rests directly upon Laramie beds in apparently perfect conformity."[1] Vertebrate fossils were not found, but the invertebrate fossils from the Fort Union beds at this place were submitted to Stanton, who reported that "almost all the species of the list were originally obtained near Fort Union on the Missouri River."[2]

Of Fort Union fossils in the United States National Museum, Weed says[3]: "They have been studied by Professor Knowlton, who reports that the Fort Union flora embraces 169 species. Of this number 130 species are confined to this formation. Of the 39 species found in other terranes, 21 occur in the Miocene, 14 in the Denver (post-Laramie), and 9 in the Laramie. These figures tell their own story." Knowlton states that the flora as a whole is clearly Eocene. This confirms the statement of Newberry that the floras of the Laramie and the Fort Union are totally distinct, "and that these formations should be referred to different geological horizons, the Fort Union to the Tertiary, and the Laramie to the Cretaceous." Weed gives the following table showing "the comparative sections found along the Rocky Mountain front."[4]

Age	Montana	Canada	Colorado
Eocene	Fort Union	Paskapoo 5700' { Porcupine Hills / Willow Creek	
Post Laramie	Livingston	(Erosion interval)	*b*. Denver beds *a*. Arapahoe beds
	Unconformity		Unconformity
Cretaceous	Laramie	Edmonton (Tyrrell) or Wapiti River (Dawson)	Laramie

[1] WEED: loc. cit., p. 206.

[2] Quoted by Weed, loc. cit., pp. 206, 207.

[3] WEED: loc. cit., p. 210.

[4] Loc. cit., p. 211.

This conclusion concerning the age of the Fort Union formation has been supported by the Dawsons, as shown by the following: "Dr. G. [M.] Dawson and the writer [Sir William Dawson] have, ever since 1875, maintained the lower Eocene age of our [Canadian] Laramie, and of the Fort Union group of the northwestern United States. . . . ."[1]

THE PUERCO FORMATION.

The Puerco formation is located in northwestern New Mexico at the headwaters of Puerco River, from which the formation takes its name, and where it "reaches a thickness of outcrop of about 850 feet."[2] The rocks of this formation consist of "sandstones and gray and green marls."[3] The formation is thus characterized by Wortman:[4] "The thickness of the beds is roughly estimated at 800 to 1000 feet, and as far as can be observed they lie conformably upon the Laramie."

The fossils occur at two horizons which are separated by barren strata 700 to 800 feet thick (not 30 feet as erroneously quoted by Dall in the Eighteenth Annual Report U. S. Geol. Surv., Part II, p. 347). "The lower fossil-bearing strata occur in two layers, the lowermost of which lies within 10 or 15 feet of the base of the formation. This is succeeded after an interval of about 30 feet by a second stratum in which fossils are found. . . . . Both of these strata are red clay, and at no place did we find them more than a few feet in thickness."[5]

This horizon "is especially and sharply distinguished by the occurrence of the remains of Polymastodon, which appear to be entirely absent from the upper horizon."[6] The upper horizon is richer in fossils than the lower. "The genera Chirox and Pantolambda appear to belong exclusively to the upper beds."[7]

[1] Quoted by Knowlton, Bull. V, Geol. Soc. Amer., p. 589, 1894.

[2] CLARK: U. S. Geol. Surv., Bull. No. 83, p. 138, 1891.

[3] CLARK: loc. cit., p. 138.

[4] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 1, 1895.

[5] WORTMAN: quoted by Osborn, loc. cit., p. 2.

[6] *Ibid.* [7] *Ibid.*

Wortman believes that the upper fossiliferous horizon contains several layers, and that their vertical range is somewhat greater than that of the lower horizon." Matthew states that the "Upper and Lower Puerco beds do not contain a single species in common, and only three or four genera pass through. The two faunas are entirely distinct. Dr. Wortman proposes to call the upper beds the Torrejon formation, retaining the name Puerco for the lower beds."[1] Scott correlates the Puerco with the Cernaysien of Europe.[2]

THE WASATCH FORMATION.

The Wasatch formation occurs in a large area in Utah, Wyoming, and Colorado. It is equivalent to the Vermillion Creek of King; Bitter Creek of Powell; and Coryphodon beds of Marsh. The fossils indicate that the rocks were deposited in fresh water. "From the outcrops thus broadly sketched it is clear that a single lake extended from longitude 106° 30′ to 112°, stretching northward probably over the greater part of the Green River Basin, and southward to an unknown distance."[3]

The Wasatch beds lie upon the Cretaceous with a discrepancy in dip, as shown by King, of 0° to 25° in many places. Clark says:[4] "The Wasatch strata throughout much of their extent are conformable to the Laramie, but in western Wyoming and eastern Utah a marked unconformity is exhibited." King thus describes the Wasatch formation, which he names Vermillion Creek:[5] "It is made up of a heavy gritty series at the base, which in the region of Vermillion Creek and north of Evanston is gray, but as displayed at Echo Canyon and East Canyon Creek is characterized by the presence of enough red sandstones and clays to give it more of a brick or in places a deep pinkish color. The middle members are of finer material and are more intercalated with clays, while the upper part of the series has shown wherever the group comes in contact with the Green

[1] Science, n. s., Vol. VII, p. 852, 1897. [2] Science, n. s., Vol. II, p. 499, 1895.

[3] KING: U. S. Explorations of the 40th Parallel, Systematic Geol., Vol. I, p. 374.

[4] Loc. cit., p. 139. [5] Loc. cit., p. 375.

River series, is made up of striped and banded sandstones, varying from gray to yellow, white, and red, with prevailing white and red tints. As regards the relations of this with the underlying group, it should be repeated that the evidence has finally accumulated so that there can be no longer a doubt where to draw the line between the Cretaceous and the Tertiary series. I unhesitatingly say that the bottom of the Vermillion Creek is the base of the Tertiary, and that it rests in essential unconformity (though locally in accidental conformity) upon the Cretaceous."

Scott, in a paper read before the British Association, correlates the Wasatch with the Suessonien of Europe.[1]

THE BRIDGER FORMATIONS (including Green River and Wind River).

The Bridger is divided by Scott[2] into two substages, namely, Wind River substage (=Green River substage), and Bridger substage. The Bridger deposits are less extensive than the Wasatch.[3] The Wind River beds lie chiefly in the valley of Wind River, Wyoming, east of the Wind River Mountains. The width of their outcrop is from one to five miles, and its length about 100 miles. The beds reach a thickness of 1000 feet, and are composed of sandstones and shales.

The Green River beds are in the valley of the Green River in Wyoming, Colorado, and Utah, on the west side of Wind River Mountains. Paleontological evidence shows them to be of essentially the same age as the Wind River beds, hence the appropriateness of this name for both series. Outliers of Green River beds occur west to about longitude 116° W. in Nevada, and King interprets this fact as showing that the waters in which they were deposited were probably bounded by the Piñon Mountains.[4] "The Green River series rests for the most part unconformably upon the horizontal as well as the highly inclined Vermillon Creek [Wasatch] beds."[5] These beds are described

[1] Science, n. s., Vol. II, p. 499, 1895. [2] Introduction to Geology, p. 496, 1897.
[3] SCOTT: loc. cit., p. 499. [4] Loc. cit., p. 393. [5] KING: loc. cit., p. 378.

as "calcareous sands and slightly siliceous limestones, which are overlaid by remarkably fissile shales." The limestones are about 800 feet thick; the shales 1200 feet thick. The beds contain fresh-water fossils but "no brackish-water forms whatever."[1]

The formation of the Bridger substage is described by King[2] as follows: "Throughout the middle of the Bridger Basin, it rests in positions of complete horizontality, and throughout its whole extent shows no evidence of orographical disturbance, such as could be registered in local changes of angle. The aggregate thickness of the beds of this group is estimated as between 2200 and 2500 feet. The material is almost wholly made up of fine sand and clay, arranged in varying proportions and occasionally slightly changed by calcareous mixtures." Scott correlates the Bridger with the Parisien of Europe.[3]

THE HUERFANO FORMATION

The Huerfano beds in Huerfano county, Colorado, were first described by R. C. Hills in 1888. He estimated the thickness to be 8000 feet and made three divisions of the beds. In 1891 Hills identified the upper beds, which consist of clays, soft shales and sand, as Bridger, and estimated its thickness at 3300 feet. Below this lie the Cuchara beds 300 feet thick, and below the Cuchara are the Poison Canyon beds 3500 feet thick. The lower two divisions he considered Lower Eocene. In 1897 Osborn and Wortman visited the region and arrived at the following conclusions[4]: (1) "That west of Huerfano Canyon the variegated marls, clays, soft shales and sands aggregate only 800 to 1000 feet in thickness and are nearly horizontal in position. They may be positively divided into upper beds equivalent to the Bridger,[5] and lower beds, equivalent to the Wind River or Upper Wasatch.

[1] KING: loc. cit., p. 389. [2] Loc. cit., p. 400.

[3] Science, n. s., Vol. II, p. 499, 1895.

[4] OSBORN: Bull. Amer. Mus. Nat. Hist., Vol. IX, p. 250, 1897.

[5] "Bridger" and "Wind River" appear to be used in the sense of "Bridger substage" and "Wind River substage" respectively as used by Scott. Cf. SCOTT'S Introduction to Geology, p. 496, table.

These constitute the only true Huerfano deposits. (2) That the Cuchara and Poison Canyon beds are unconformable with the Huerfano beds and older than the Eocene, probably marine cretaceous as partly determined by the presence of a species of *Baculites* in the yellow sandstone of the typical Poison Canyon section. (3) That the present canyon of the Huerfano River cuts through the base of the main anticlinal axis of post-Laramie origin, which formed the eastern boundary of the lake. This axis extended to the south so as to include the base of Silver Mountain toward the Cuchara divide; but it lies from three to seven miles west of the anticlinal axis described by Professor Hills. (4) That the Huerfano lake deposition did not extend as far to the east or south as Spanish Peaks, and that the variegated beds observed there are of older origin. This would materially affect the geological age of the prominent neighboring laccoliths."

From the above conclusions it will be observed that the Huerfano beds are much more restricted geographically than was supposed by Hills. They occupy a part of the basin of the upper part of Huerfano River, between the Wet Mountains on the northeast and the Sangre de Cristo and Culebra ranges on the west and south. Osborn thinks the beds were formed by the damming of the Huerfano River by a post-Laramie axis of uplift which was afterward trenched by the river. The lake was thus drained.

It appears from Osborn's conclusions that the two divisions of the Huerfano beds represent the two substages of the Bridger stage of Scott. The name Huerfano should be restricted to one of these divisions. The other division should receive a new name.

THE UINTA FORMATION (=Brown's Park group of Powell).

The Uinta formation was named by King from the Uinta Mountains, on the flanks of which its outcrops occur. The Uinta is described as follows[1]: ". . . . it is possible that this group was deposited continuously, at least in part, with the Bridger

[1] Quoted by Clark, loc. cit., p. 143.

group, but at the places where the junction between the two groups have been seen in this region there is an evident unconformity, both of displacement and of erosion. The group consists of fine and course sandstones, with frequent layers of gravel, and occasionally both cherty and calcareous layers occur. The sandstones are sometimes firm and regularly bedded, and sometimes soft and partaking of the character of bad land material. The color varies from gray to dull reddish-brown, the former prevailing north of the Uinta Mountains, the latter south of them." King says the lower members of the Uinta group are, "chiefly rough, gritty conglomerates, passing up into finer grained sandstones, and at certain points developing creamy, calcareous beds."[1]

The vertebrate fossils show the Uinta to be a fresh water deposit. Scott notes that a considerable break [physical ?] occurs between the Bridger and the Uinta, and that earth movements took place at this time. He makes the Uinta equivalent to the Paris gypsum deposits[2]. Peterson finds the following succession of strata in the Uinta basin.[3] (1) Wasatch; (2) conformably upon Wasatch, Green River; (3) conformably upon Green River, a series of hard, brown sandstones, alternating with greenish-gray clays; (4) conformably upon this are layers of coarse, brown sandstone alternating with shales; (5) "*true Uinta* or Brown's Park beds of a fine grained soft material . . . . of brick-red color." These last named beds are about 600 feet thick. Describing the highest three (3, 4, and 5 above) Peterson says:[4] "This uppermost strata [stratum] of the Uinta basin has hitherto been reported as resting unconformably upon the Bridger sediment, but no observable breaks were found to distinguish the true Uinta from underlying Bridger sediment. So the writer found it necessary in collecting fossils to divide the beds overlying the Green River shales into three different levels, which are here arranged alphabetically in ascending position

[1] Loc. cit., p. 405. [2] Science, n. s., Vol. II, p. 499, 1895.

[3] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 73, 1895.

[4] Quoted by Osborn, loc. cit., p. 74.

[A being lowest]: Horizon C, true Uinta beds 600 feet thick, sandstones and clays brownish and reddish, ferruginous . . . . "Horizon B, 300 feet thick. Soft coarse sandstones and clays. Horizon A, 800 feet thick. Hard brown sandstones immediately overlying the Green River shales." Commenting upon the above field notes Osborn says[1]: "These excellent observations supply one of the most important links in the American lake faunal chain, namely that between the Washakie[2] and the Uinta. The explorations of the present year, 1895, may modify these results, but it is certain we have now not only established a complete faunal transition from the Bridger and Washakie beds upon the one side, to the true Uinta level or Horizon C upon the other, but have demonstrated a closer connection between the fauna of this basin and that of the lowest White River Miocene."

THE AMYZON FORMATION

Under this name Cope has described beds in Elko county, Nevada; in South Park, Colorado; and in central Oregon. He regards them as belonging to the "later Eocene or early Miocene eras."[3] King described and mapped the same beds of Nevada as of Green River age.[4]

Cope thus describes the beds of Oregon: "The regions of the John Day River and Blue Mountains, furnish sections of the formations of central Oregon. . . . . Below the Loup Fork follows the Truckee [Neocene] group, so rich in extinct mammalia, and below this a formation of shales. These [shales] are composed of fine material and vary in color, from a white to a pale brown and reddish-brown They contain vegetable remains in excellent preservation, and undeterminable fishes. The *Taxodium* nearly resembles that from the shales at Osino, Nevada, and on various grounds I suspect that these beds form a part of

[1] Loc. cit., pp. 74, 75.

[2] Beds belonging to the upper part of the Bridger substage lying east of Green River in southern Wyoming. Cf. Clark, U. S. Geol. Surv., Bull. No. 83, pp. 117, 142.

[3] Amer. Nat., Vol. XIII, p. 332, 1879.

[4] U. S. Geol. Explorations of the 40th Parallel, Vol. I, Systematic Geol., p. 393, 1878.

the "Amyzon Group" (*American Naturalist*, June 1880), with the shales of Osino and of the South Park of Colorado."[1] The Amyzon beds of Nevada appear in the accompanying map. Those of Colorado and of Oregon are not here mapped.

THE MANTI FORMATION

Cope has described this formation as follows:[2] "There is, however, a series of calcareous and silico-calcareous beds in central Utah, in Sevier and San Pete counties, which contain the remains of different species of vertebrates than those which have been derived from either the Green River or Amyzon beds. These are *Crocodilus*, sp., *Clastes cuneatus* Cope, and a fish provisionally referred to *Priscacara* under the name *P. testudinaria* Cope. There is nothing to determine to which of the Eocenes this formation should be referred, but it is tolerably certain that it is to be distinguished from the Amyzon beds. In its petrographic characters it is most like the Green River, as it consists in large part of shales. The laminae are generally thicker than those of Green and Bear rivers. The genera *Crocodilus* and *Clastes* have not been found heretofore in Green River beds, although they are abundant in the formations deposited before and after that period. Until its proper position can be ascertained, I propose to call the formation the Manti beds."

Some years later Cope regarded these beds as of probably Wind River age. He says, "A probable second locality of this [Wind River] formation is known in eastern Utah, in the Wasatch Mountains. This formation is known as the Manti beds."[3]

THE MOJAVE FORMATION

Fairbanks has described[4] a formation in southeastern California which is probably Eocene. "On the northern slope of the El Paso range, between Mojave and Owen's Lake, there is a series of beds of clays, sandstone, volcanic tuffs, and interbedded

[1] Proc. Amer. Philos, Soc., Vol. XIX, p. 61, 1880.

[2] Amer. Nat., Vol. XIV, pp. 303, 304, 1880.

[3] *Ibid.*, Vol. XXI, p. 454, 1887.

[4] Geology of eastern California, Am. Geol., Vol. XVII, p. 63, 1896.

lava flows. These are probably 1000 feet or more in thickness and extend over a considerable area between the El Paso range and the Sierra Nevadas. . . . . They are finely exposed in Red Rock canyon and about Black Mountain. . . . . The beds are tilted northward at an angle of 15–20 degrees. . . . . Impressions of leaves occur in the clay immediately above the seam of coal. These were submitted to Dr. F. H. Knowlton who says: 'I have looked over the three small fragments of fossil plants from the Mojave desert with the following result: Two species are represented, *Spindus affinis* Newb., and *Anemia subcretacea* (Sap.) Ett. and Gard. . . . . The plants indicate a Tertiary age without doubt, and they seem to belong to the Eocene. Both species have quite a wide distribution geographically and are confined, with several unimportant exceptions, to the Eocene.'"[1]

EOCENE OF BATES HOLE, WYOMING

In the valley of Bates Creek, Natron county, Wyo., fossiliferous Eocene beds occur. They have been but recently recognized and no published account of them is known to the writer.

THE KENAI FORMATION

The coal bearing beds typically seen on Kenai peninsula, Cook Inlet, Alaska, "but widely spread in British Columbia and over the coast of Alaska and its adjacent islands" are called by Dall and Harris the Kenai group.[2] Cretaceous Aucella beds lie beneath the Kenai, but whether marine beds of the same age as Kenai intervene is uncertain.[3] "In Alaska, at Cook's Inlet, at Unga Island, at Atka and at Nulato in the Yukon valley we find the leaf beds of the Kenai group immediately and conformably overlain by marine beds containing fossil shells which are common to the Miocene of Astoria, Oregon, and to middle and southern California."[4] Kenai rocks consist of "great thicknesses of somewhat loosely consolidated conglomerates, sandstones, and shales, all generally greenish in character. They contain everywhere

[1] FAIRBANKS: loc. cit., pp. 67, 68.

[2] DALL and HARRIS, Bull. No. 84 U. S. Geol. Surv., pp. 234 et. seq., 1892.

[3] *Ibid.*, loc. cit., p. 251.

[4] *Ibid*, loc. cit., p. 251.

plant remains and frequent seams of lignite, and rest unconformably upon the older formations."[1]

The conclusion concerning the age of the Kenai is based upon its fossil plants and upon its stratigraphic relations. In 1892 Dall, after a summary of the evidence, concludes that the Kenai "is probably of Eocene age. . . . . "[2] In 1896 Dall says, "When we consider that the Oligocene Aturia bed is immediately and conformably overlain at Astoria, Oregon, by shales and sandstones undoubtedly equivalent to the Alaskan marine Miocene, and that the latter, in like manner, immediately and conformably overlies the Kenai group it must be considered that the view that the latter is Oligocene seems highly probable."[3]

In the following year Dall places the Kenai beds in the Eocene, remarking that, "They are with little doubt coeval with the Atane beds of Greenland and other arctic leaf-bearing strata. Their exact horizon is doubtful, but some of the plants appear to be common to the lignitic beds of the Mexican gulf coast, and they are provisionally placed here awaiting more definite information."[4]

BRACKISH WATER DEPOSITS

THE PUGET FORMATION

The Puget formation occurs in Washington in the Puget Sound basin upon the western flank of the Cascade range, extending to Burrard's Inlet, British Columbia. At Comox and elsewhere in Vancouver Island. On the eastern side of the Cascade Mountains beds occur which are lithologically like the Puget formation and probably belong to it.[5] No fossils have been found in these beds east of the mountains. The Puget formation is thus described by Willis and Smith:[6]

[1] SPURR: Eighteenth Ann. Rep. U. S. Geol. Surv. for 1896–7, Part III, Economic Geology, p. 194.

[2] DALL and HARRIS: loc. cit., p. 252.

[3] DALL: Seventeenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part I, pp. 841, 842.

[4] Eighteenth Ann. Rep. U. S. Geol. Surv., 1896–7, Part II, p. 345.

[5] SIR WILLIAM DAWSON: Trans. Roy. Soc. Can., n. s., Vol. I, pp. 137, 138, 1895.

[6] Geol. Atlas of the U. S., Tacoma Folio, Washington, 1899.

The Puget formation consists of interbedded sandstones, shales and coal beds aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture, and color, and are frequently cross stratified. Their composition ranges from a typical arkose, consisting of slightly washed granitic minerals to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. Conglomerates and concentrated quartz sands have not been observed. The variations in color are not such as to distinguish upper and lower sections of the formation. In general the strata are similar and are similarly interbedded from top to bottom.

The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron, and generally more or less carbonaceous matter, which varies in character from finely divided organic material to large leaves and stems. . . . .

Carefully measured sections show that the Puget formation contains more than 125 beds which would attract the attention of a prospector searching for coal. They range from one to sixty feet in thickness, and the workable coal beds in any one section vary from five to ten in number. The valuable coal is found in the lower 3000 feet of the formation as at Carbonado, Wilkison, Burnett and Green River.

The Puget formation contains an abundant flora. Fossils are found throughout the Puget formation. These are brackish-water forms. No marine forms have been found in the Puget beds. Willis thinks the beds were laid down in an estuary in which the northern Cascade range formed a peninsula, and the Olympic Mountains an island.[1]

In 1895–6 Willis made collections "from definitely determined stratigraphic horizons on Green River, above Burnett, on South Prairie Creek, and on Carbon River near Carbonado. A preliminary examination of the fossil plants enables Knowlton to report that the lower beds of the series are Eocene, whereas the upper beds may be of Miocene age. . . . . The measured sections of the Puget series exhibit a total thickness of 5800 feet on Green River, 5500 feet on South Prairie Creek, and 5480 feet in Carbon River Canyon. None of these measures is complete. . . . . The sections probably overlap. . . . ."[2]

[1] Cf. CLARK: loc. cit., p. 197.

[2] WILLIS: Bull. Geol. Soc. Amer., Vol. IX, pp. 5, 6, 1898.

On the evidence furnished by fossil plants Sir William Dawson correlates the Puget formation with the Fort Union formation as will be seen from the following quotation:[1]

> In summing up the results of this study of fossil plants from the Tertiary of southern British Columbia, it appears from a comparison with the flora of the Upper Cretaceous Nanaimo series, that the Burrard's Inlet species are distinct and of more modern aspect. On the other hand they are also distinct from those of the older Oligocene or older Miocene deposits of the Similkameen district and other parts of the interior of British Columbia. Between these they occupy an intermediate position; in this respect corresponding with the Laramie of the interior plains east of the Rocky Mountains. They also resemble this formation in the general facies of the flora, which is not dissimilar from that of the Upper Laramie or Fort Union group. We may thus refer the plants [from Burrard's Inlet] now in question to the Paleocene or Eocene, and regard them as corresponding with those of the Atanekerdluk beds in Greenland, the lignitic series of the McKenzie River, and the beds [Kenai?] holding similar plants in Alaska. Thus the opinion expressed in 1890, from the very small collection then available was substantially correct; and I find that the late Dr. Newberry had arrived at a similar conclusion from the study of the plants of the Puget group in Washington territory. This flora thus serves to fill up one of the gaps in our western series of fossil plants, namely, that between the Cretaceous and the Lower Miocene. How completely it may fill this gap we do not know at present. . . . .

THE ARAGO FORMATION

The typical outcrop of this formation is at Cape Arago, Oregon. The beds are chiefly sandstones and shales, and dip toward the northeast at an angle of about 30°. Their thickness is 3000 feet. They contain characteristic Eocene fossils.[2] Diller[3] divides the Arago formation at Coos Bay into the Pulaski formation and the Coaledo formation. The Pulaski is the lower. "The Coaledo formation is characterized not only by the presence of coal, but also by the relatively large proportion of beds containing brackish-water fossils. In the other portion [Pulaski] of the Arago formation of the Coos Bay

[1] SIR WILLIAM DAWSON: Proc. Roy. Soc. Can., n. s., Vol. I, pp. 150, 151, 1895.

[2] DALL: Eighteenth Ann. U. S. Geol. Surv., 1895–6, Part II, p. 343.

[3] Nineteenth Ann. Rep. U. S. Geol. Survey, 1897–8, Part III, p. 320.

quadrangle more than mere traces of coal do not occur, and strata containing brackish-water fossils are rare."[1]

THE MARINE FORMATIONS

THE MARTINEZ FORMATION

The name Martinez was first applied by Gabb[2] to a division of Cretaceous rocks of California. The name comes from the town Martinez, near which typical exposures occur. In recent years the formation has been studied critically by Stanton and by Merriam. "Mr. Stanton has shown the Martinez of Gabb to consist of two parts, one characteristic Cretaceous and inseparable from the Chico group, the other being more closely related faunally and stratigraphically to the Tejon-Eocene than to Chico."[3] The latter was called Lower Tejon by Stanton. Merriam observes that at numerous points on the Pacific coast where the Tejon has been found it always contains an easily recognized fauna. From studies of the faunas in the vicinity of Martinez he proposes (following a suggestion of Stanton) to apply the name Martinez to the Lower Tejon of Stanton.

> In the vicinity of Martinez, the Martinez and Tejon groups form an apparently conformable series between two and three thousand feet in thickness and about equally divided between the two. The faunas, though overlapping, are in the main quite distinct. . . . While some intermingling of species exists, it is not greater than we should expect to find in adjoining groups or periods. . . . The two sets of strata, or two faunas, while belonging perhaps to the two series, represent different periods in the geological history of California, periods quite as distinct so far as faunal evidence is concerned, as the Miocene and Pliocene, or the Pliocene and Quaternary.[4]

The Martinez formation is characterized as "comprising, in the typical locality between one and two thousand feet of sandstones, shales and glauconitic sands," forming "the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty

[1] DILLER: loc. cit., p. 320.

[2] Cf. MERRIAM: JOUR. GEOL., Vol. V, p. 767, 1897.

[3] MERRIAM: loc. cit., p. 768.

[4] MERRIAM: loc. cit., p. 774.

species of which the greater portion is peculiar to itself."[1] Its fossils are marine.

THE TEJON FORMATION

This formation was named[2] in 1869 by Whitney, from Fort Tejon, Cal. "The deposits are chiefly conglomerates, sandstones, and shales, in which beds of lignite are not infrequently intercalated, and which less often contain bands of calcareous rock." Clark[3] quotes Whitney (?) as stating that "The conglomerates are very coarse, containing many bowlders from three to six inches in diameter of granite and metamorphic rocks. . . . Portions of the sandstones are very fossiliferous. . . . The strata are very much disturbed, both dip and strike being very variable. . . ." The fossils are marine. Beneath the Tejon is the Chico formation. White, Becker and others state that the Tejon of California lies conformably upon the Chico — the two forming one series.[4] Yet writing of the series at New Idria, Cal., White says, "There is near its middle, a recognizable change of aspect of the strata. . . ."[5] Becker says "The Tejon strata of New Idria are mostly heavy-bedded sandstones of a peculiarly light color, which thus distinguishes them from the tawny Chico standstones."[6]

It is stated also that the Miocene overlies the Tejon conformably. But near Martinez Merriam has shown a pronounced change of fauna, as has been already mentioned. Diller[7] has shown that "All of the facts yet known indicate that in Oregon and northern California there is a faunal and stratigraphic break between the Chico and the Tejon." Perhaps the conformity reported from southern California will be found to be local, or only apparent. Certainly the structural and faunal relations already discussed separate the Tejon from the Chico and from the Martinez. The Tejon is a distinct formation. Near Merced falls, near the boundary of Merced and Mariposa counties,

[1] MERRIAM: loc. cit., p. 775.

[2] Cf. CLARK: loc. cit., p. 100.

[3] CLARK: loc. cit., p. 101.

[4] Cf. CLARK: loc. cit., p. 102.

[5] Quoted by Clark, loc. cit., p. 102.

[6] *Ibid.*

[7] Bull. Geol. Soc. Amer., Vol. IV, p. 220

California, Turner and Ransome describe[1] small patches of Tejon sandstones capping the hills. "This rests almost horizontally upon the nearly vertical edges of the Mariposa [Jura-Trias] slates. . . . The sandstones are overlain to the west by the light colored sandstones of the Ione formation. The two series are probably not absolutely conformable, as the Ione transgresses onto the rocks of the Bed-rock series farther west." Tejon fossils are found in this formation. The Tejon is found in Oregon in the valley of the Willamette River at Albany and at other localities. Clark states that "The Tejon strata of Oregon have been found in a few widely separated localities in the central and northern portions of the state. The most southern yet observed is Coos Bay."[2] But he cites no literature on the the subject, and Diller, in his discussion of the "Coos Bay Coal Field,"[3] makes no mention of Tejon strata.

The Astoria beds at the mouth of Snake River are regarded as Oligocene.

THE UMPQUA FORMATION.

The Eocene described in the Folio of the Roseburg quadrangle, Oregon, rests directly upon an eroded surface of the Upper Cretaceous (Myrtle) formation.[4] There are evidences of considerable erosion in the region before the deposit of the Eocene beds. This leads Diller to believe that Chico may have been present and eroded away. Diller describes the Eocene sedimentary beds under the names "Umpqua formation," from the Umpqua River on which the outcrops occur: "Wilbur tufflentils;" and "Tyee sandstone." The most extensive and important of these is the Umpqua. It lies unconformably upon Cretaceous rocks, and "stretches far beyond the Roseburg quadrangle and plays an important rôle in the makeup of the whole country west of the Cascade Range." The

[1] Geol. Atlas of U. S., Sonora Folio, Calif., 1897.

[2] U. S. Geol. Surv., Bull. 83, p. 103.

[3] Nineteenth Ann. Rep. U. S. Geol. Surv. for 1897-8, Part III, Economic Geology, p. 309 et seq.

[4] DILLER: Geol. Atlas U. S., Roseburg Folio, Ore., 1898.

"formation is composed of an extensive series of conglomerates, sandstones and shales, with terraces here and there of calcareous siliceous beds, which, although of small extent, on account of their exceptional character are treated separately as the Wilbur formation."[1] The Umpqua formation has a maximum exposure of about twelve thousand feet The beds thicken toward the northwest. The bowlders of the Umpqua formation become larger toward the east and south, showing that the land from which they were derived lay in this direction. In places the Umpqua contains abundant marine fossils, *Cardita planicosta* and *Turritella uvasaria* being typical Eocene forms. Thin, small beds of coal also occur.

THE TYEE SANDSTONE

The Tyee sandstone occupies a small area in the vicinity of Roseburg, Ore. "It immediately overlies the Umpqua formation, from whose sandstones it differs chiefly in being heavier bedded and containing more conspicuous scales of mica."[2] It reaches a thickness of about 1000 feet. In places it contains characteristic marine Eocene fossils. The position of the Umpqua and Tyee beds in the geological column cannot be given with certainty. They overlie the Myrtle beds which, according to Stanton, belong to "the lower half of the Upper Cretaceous."[3] Upon the Umpqua, in apparent conformity, lies the "Oakland limestone-lentils" of "probably Oligocene, most likely Upper Oligocene" age.[4] From these relations, from their geographical position and from their fossils I place the Umpqua and Tyee provisionally in the column above the Tejon. If this be their true position they form the latest marine Eocene beds known on the Pacific coast.

THE ATURIA FORMATION

The Aturia beds occur at the water's edge at Astoria, Ore. Formerly they were not distinguished from the overlying shales and sandstones. But in 1880 Condon[5] showed that they are

[1] DILLER: loc. cit. [2] *Ibid.* [3] Quoted by Diller, loc. cit.

[4] DILLER: loc. cit. [5] Amer. Naturalist, Vol. XIV, 1880.

distinct and that the presence of *Aturia ziczac* determines these lower beds to be Eocene or Oligocene. The overlying shales and sandstones do not contain this fossil and are regarded as Miocene. In his "Correlation tables of Tertiary formations: data to 1895" Dall places the Aturia beds in Lower Oligocene, Astoria shales in Upper Oligocene, and Astoria sandstones in Miocene.[1]

UNFOSSILIFEROUS FORMATIONS

THE SPHINX CONGLOMERATE FORMATION

Sphinx conglomerate is the name applied by Peale[2] to a group of nonfossiliferous beds covering an area of about two square miles, but having a thickness of 2000 to 3000 feet. The formation occurs in the Madison Mountain range, Montana. The beds consist of "reddish sandstones and coarse conglomerates of limestone pebbles and bowlders cemented with a reddish sand." They are horizontal and stratified. They are described and mapped as Eocene.

THE PIÑON CONGLOMERATE FORMATION

Weed describes[3] briefly, under the name Piñon conglomerate, certain beds which occur in the southern part of the Yellowstone National Park. He says they consist of a series of conglomerate beds with local intercalations of sandstone, the formation resting unconformably upon the upturned Laramie (Cretaceous)." No fossils are mentioned and they are presumably nonfossiliferous. They are described and mapped as Eocene.

THE SAN MIGUEL FORMATION

The San Miguel formation was named by Purington[4] and referred by him to the Eocene "because of the great unconformity at its base and because it underlies the volcanic complex, which is thought to be of Eocene age in the portions here developed." It occurs near Telluride and Silverton, Col., and rests

[1] Eighteenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part II, pp. 327–348.

[2] Geol. Atlas of U. S., Three Forks Folio, Mont., 1896.

[3] Geol. Atlas of U. S., Yellowstone National Park Folio, 1896.

[4] Geol. Atlas of U. S., Telluride Folio, Col., 1899.

unconformably upon Mesozoic and Paleozoic strata. No fossils have been reported from it. It consists of a coarse, variable conglomerate. Its thickness varies from a few feet to 1000 feet. It is thicker toward the west and dips toward the east.

Some geologists, however, would dispute the right of the San Miguel formation to a place among the Eocene formations on the grounds on which Purington places it there. If it is admitted to the Eocene epoch, there would seem to be no good reason for excluding a number of other formations, among which are the Denver and the Arapahoe beds. Geologists appear to be not fully agreed upon the criteria that shall determine the base of the Eocene.

INTERPRETATION

Having reviewed the various Eocene formations of the region, we may now consider some of the conditions presented by the region as a whole, and some of the problems involved in its history.

Physiography and Climate.— On the Pacific coast the Tejon as now known was deposited in marine water which occupied the great valley of California and western Oregon. It is not known whether the beds of Oregon and California were connected with each other or not. This interior sea in which the Tejon of California was deposited probably connected with the ocean in southern California. There may have been several connecting channels. No definite knowledge exists upon the subject. Before the end of the Tejon deposition the Chico area in Oregon, which had been land and subject to erosion, went down beneath the sea, and beds of Upper Tejon age, possibly underlain by Martinez, were deposited upon it. Probably the same subsidence admitted the sea in which the Umpqua and Tyee beds were deposited a little farther to the southwest. If so, these beds are to be correlated with the Tejon. The correlation of these geographically separated beds must finally be decided by their fossils.

The plants of the Kenai formation indicate a temperate climate at the time of their growth. This climate probably

prevailed over North America, Greenland and Europe, reaching to Spitzbergen. Dall says[1] it may be considered as reasonably certain "that the period during which in the arctic regions the last temperate flora flourished was in a general way the same for all parts of the arctic. It would seem highly improbable that a temperate climate should exist in Spitzbergen and not at the same time in Greenland and Alaska, or *vice versa*." Moreover the nature of the plants of the regions named forms the basis of this statement. The Kenai beds are regarded as fresh water deposits and represent a low land area, which was subsequently still further depressed allowing the Miocene sea to cover it. Dawson[2] says:

> It would be rash to decide on the climatal conditions on the west coast of America in the Eocene period, from the plants yet known. But so far as they can give information we may infer that the Cretaceous climate was somewhat warmer than that of the Eocene, but that both attained a higher temperature than that of the present day in the same latitudes, while in the Miocene age the climatal conditions were not very different from those now prevailing in the region.

The Fort Union beds are perhaps the oldest that have been certainly determined to be Eocene. They occupy the plains region of the north. Their limit to the south is unknown, but Haworth[3] believes that near the beginning of Eocene time Tertiary deposits spread continuously from the Dakota-Nebraska area over western Kansas, Indian Territory, and Texas.

Immediately succeeding or perhaps in part contemporaneous with the Fort Union deposits a series of so-called lake deposits was formed on the plains of the summit region bordering the Rocky Mountains on the east. Elevation or warping of the continent and especially of the mountains of this region appears to have checked the drainage in certain directions, so as to form lakes. The oldest and lowest of these deposits are toward the south and west (Puerco); the newest and highest toward the north and east. Probably during Eocene time the uplift in this

[1] Seventeenth Ann. Rep. U. S. Geol. Surv. 1895-6, Part I, p. 839.

[2] Proc. Roy. Soc. Can., n. s., Vol. I, p. 151, 1895.

[3] The Univ. Geol. Surv. of Kans., Vol. II, p. 253, 1896.

region was greater in the southwestern part than in the northeastern part.

THE ORIGIN OF THE SO-CALLED LAKE DEPOSITS

The stratified deposits of the Wasatch, Bridger, Uinta, and others of like nature have been regarded and referred to as lake deposits. Dutton seems to have been the first to recognize and to point out the fact that some of them are not of lacustrine origin. As early as 1880, in his report on the High Plateaus of Utah he says:[1]

> There is another class of conglomerates which claims our special attention. These are of alluvial origin, formed, not beneath the surface of the sea nor of lakes, but on the land itself. They do not seem to have received from investigators all the attention and study which they merit. . . . . Throughout great portions of the Rocky Mountain region they are accumulating today upon a grand scale and have accumulated very extensively in the past.

He then describes the formation and coalescence of alluvial cones containing well-stratified material. Yet this idea of subaërial deposition seems not to have been further emphasized either by Dutton or by others. For a little later he writes[2] "The whole region [High Plateau], with the exception of the mountain platforms and preëxisting mainlands, has passed through this lucastrine stage."

In 1896 Gilbert[3] clearly interpreted certain stratified deposits of Colorado as fluviatile. He speaks thus of the Upland sands and gravels of the Arkansas River basin:

> Whatever the cause the streams which flowed from the mountains onto the plains, and thence eastward across the plains, ceased to carve valleys in the region of the plains, and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions and they then came to flow in succession over all parts of the plains, and to distribute their deposits widely, so that the whole plain of the district here described was covered by sands and gravels brought from the canyons and valleys of the Rocky Mountains.

[1] Geol. of the High Plateaus of Utah, pp. 219 et seq., 1880.

[2] The Grand Canyon of the Colorado, p. 216, 1882.

[3] Seventeenth Ann. Rep. U. S. Geol. Surv. for 1895–6, Part II, pp. 575, 576.

In studying the Tertiary deposits of Kansas Haworth reaches similar conclusions. He says:[1]

The relative positions of gravel, sand and clay of the Tertiary over the whole of Kansas . . . . correspond much better to river deposits than to lake deposits. . . . It is quite possible that during Tertiary time . . . . lesser local lakes and lagoons and swamps and marshes may have existed in different places and for varying lengths of time. But when we consider the Kansas Tertiary as a whole and yet in detail, it must be admitted that the materials themselves have many indications of river deposits and a very few of lake deposits.

Matthew,[2] in discussing the question whether the White River Tertiary is an eolian formation, considers the objections to the lacustrine hypothesis and gives reasons for his believing it to be of eolian origin. He reaches the conclusion that the "White River clays in Colorado, at least, are chiefly eolian deposits. . . . . Most of the sandstones are probably fluviatile. . . . . Some sandstones may be eolian" (407). This position, however, cannot at present be regarded as established; but the question of lacustrine origin is shown to be an open one.

In 1897 Davis,[3] in discussing the origin of the Denver formation, gives criteria for distinguishing lacustrine from fluviatile deposits. In a later publication[4] the same author compares lacustrine with fluviatile deposits as follows: "In both cases the deposits are stratified; in both cases the deposits may include fine as well as coarse materials; in both cases the area of distribution may be large as well as small; in both cases the thickness of deposits may be great as well as light; in both cases the strata may bear ripple-marks, mud-cracks, cross-bedding, and other indications of small and variable water-depth. With all these similarities, it would not be remarkable if a lake deposit were sometimes called a river deposit, or if a river deposit were

[1] The Univ. Geol. Surv. of Kans., Vol. II, p. 283, 1897.

[2] Amer. Naturalist, Vol. XXXIII, pp. 403–408, 1899.

[3] Science, U. S., Vol. VI, pp. 619–621, 1897.

[4] Freshwater Tertiary Formations of the Rocky Mountain Region. Proc. Amer. Acad. Arts and Sci., Vol. XXXV, pp. 345–373, 1900.

mistaken for a lake deposit; for the safe discrimination of the two classes of deposits must depend on their differences, not on their resemblances. While the marginal sediments of a lake may be coarse, the body of the central sediments must be fine and uniform. The marginal parts of a fluviatile deposit may also be coarser than the forward parts, but the latter may be characterized by frequent variations of texture and structure, and occasionally by filled channels and lateral unconformities" (p. 371).

Some quotations may be given to show that many descriptions of the so-called lake beds would apply equally well to river deposits. Lake terraces are "well marked between Ralston and South Boulder creeks (Colorado), where there is a *blending of lake and river terraces.*[1] Here five distinct terraces are traceable, the lake terraces extending from 100 yards to three miles eastward from the foothills, while those more distinctly of stream origin are from 200 to 700 feet in width."[2] Here the lake and river terraces are not clearly distinguished: the width of the terrace seems to be the principal criterion, and the limits assigned to lake and to river terraces overlap. According to the figures given, the river terraces here reach a width of 700 feet, while some of the lake terraces are only 300 feet wide. Again, from the same monograph, with reference to the present inclination of both Tertiary and Pleistocene deposits, it is said that there is an inclination "in round numbers of ten feet to the mile from the foothill region to the valleys of the Missouri and Mississippi;" this would not admit of the holding of lake waters."[3]

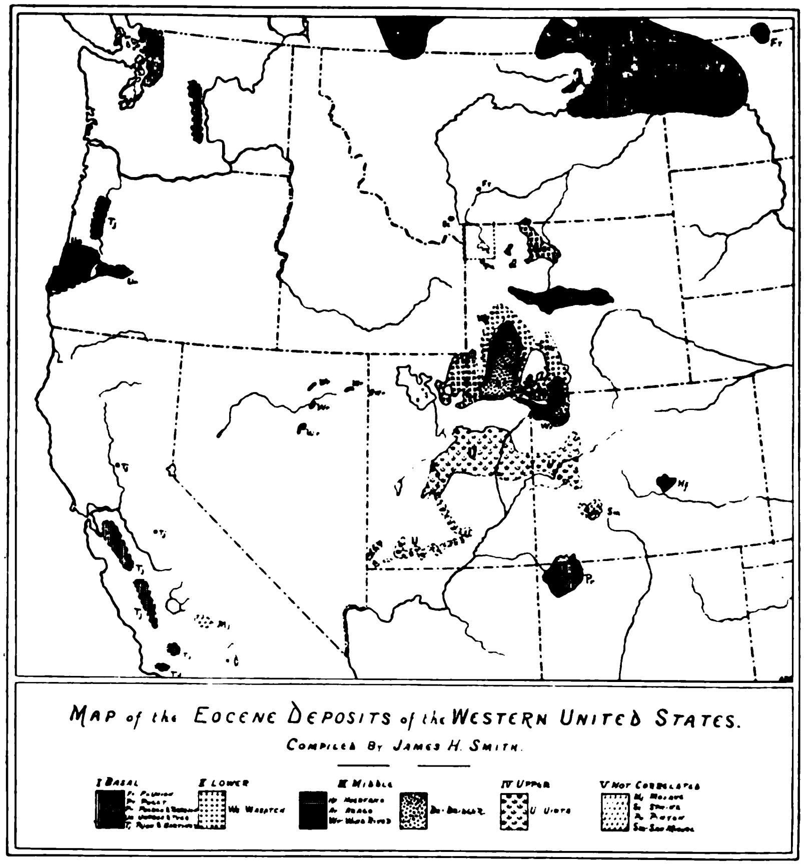
King's Report of the Survey of the 40th Parallel abounds in descriptions of so-called lake beds like the following: "Rough, gritty conglomerates, passing up into finer-grained sandstones, and at certain points developing creamy, calcareous beds" (p. 405). The most characteristic exhibition is in the basin of Vermillion Creek, where a fuller section is displayed. It is made up

[1]The italics are mine.

[2]EMMONS: Geol. of Denver Basin, Monograph XXVII. U. S. Geol. Surv., p. 9, 1896.

[3]*Ibid.*, p. 40.

of a heavy, gritty series at the base. . . . . The middle members are of finer material and are more intercalated with clays, ... while the upper part of the series . . . . is made up of striped and banded sandstones varying from gray to yellow, white and red, with prevailing red and white tints" (p. 375).



MAP OF THE EOCENE DEPOSITS OF THE WESTERN UNITED STATES.
COMPILED BY JAMES H. SMITH.

Enough has been said, perhaps, to show that no single explanation will account for the deposition of all the so-called lake beds. At present it seems probable that the deposits will be found to be in part lacustrine, in part fluviatile, and possibly in part eolian. The origin of these deposits cannot be solved by

theoretical considerations alone. Only extensive, critical study in the field will furnish the data upon which the final conclusions must be based. It will be well if the investigator shall enter the field with a clear knowledge of the facts already known, with the possibilities of the different modes of deposition and with the criteria for distinguishing these modes well in mind; and with a willingness to be led to any conclusion to which the facts may conduct him.

CORRELATION TABLE[1]

Eocene	Pacific Coast	Interior	European
Upper	Foraminiferal Shales (?)	Uinta Bridger (upper part)	Ligurien
Middle	Arago	Bridger { Bridger-Huerfano (upper) Wind River-Huerfano (lower)	Bartonien Lutetien
Lower	Kenai (?)	Wasatch	Suessonien
Basal	Tyee } (?) Umpqua } Tejon Martinez Puget	Torrejon Puerco Fort Union	Thanetien Montien

JAMES HERVEY SMITH.

[1] Cf. DALL: Eighteenth Ann. Rep. U. S. Geol. Surv., Part II, table facing p. 334, 1897. SCOTT: Science, n. s., Vol. II, p. 499, 1895. Also Introduction to Geology, p. 496. OSBORN: Science, n. s., Vol. XI, p. 562, 1900.

Many Eocene formations, not yet correlated, are omitted from the table.

EDITORIAL

DURING the spring of 1900 the Director of the United States Geological Survey has planned, with the approval of the Secretary of the Interior, an important reorganization of the Geologic Branch. In order that the significance of this step should be appreciated in all its bearings, it is desirable briefly to review the history of the administrative and scientific control within the survey. In the First Annual Report Mr. King set forth a plan of organization based on grand geographic and geologic provinces. The work being then restricted to the national domain west of the 101st meridian, four divisions were established, that of the Rocky Mountains under Emmons, that of the Colorado under Dutton, that of the Great Basin under Gilbert, and of the Pacific under Hague. Each of these divisions corresponded to a province within which the geological phenomena had a certain unity of history and character, and it was wisely argued that the work in each should be directed by a geologist familiar with the special problems of the area entrusted to him. At the same time the limited appropriations of the survey and the adopted policy of surveying the most important mining districts led to a concentration of effort upon Leadville, Eureka, and the Comstock Lode, so that initially comparatively little progress was made in solving the broad geologic problems presented to each division. The principal contributions which the West yielded to the philosophy of the science were made by the surveys through whose consolidation the Geological Survey was created. With the growth of the survey and the addition to its corps of many of the leading minds in American geology, more numerous geographic divisions were established and their limits became more artificial. Thus in the Sixth Annual Report we find enumerated, in addition to the ones first established, the Division of Glacial Geology (Chamberlin), the Division of Volcanic Geology

(Dutton), the Division of the Crystalline Schists of the Appalachian and Lake Superior Regions (Pumpelly and Irving respectively), the Appalachian Region (Gilbert), and the Yellowstone Park (Hague). As divisions became more numerous and restricted, the administrative machinery became more complex, and the opportunities afforded the geologists in charge to study broad problems became more and more limited. Finally it was found that the administrative relations were not only difficult but expensive, since they involved the maintenance of independent offices and clerks, and in the interests of economy and efficiency the system of geographic divisions was abolished in 1893. In its place was substituted an organization by parties, of which there were at first twenty and subsequently nearly double that number, each acting independently of the other except in so far as they were all brought into coöperation through the Director and the Assistant in Geology. Broad coördination of scientific work was for the time being subordinated to the accumulation of facts, especially in the form of geologic maps, rather than to the consideration of philosophic problems. After six years of this activity in the working out of special problems, the time has come for broader supervision and coördination of work, and to this end the following appointments have been made:

GEORGE F. BECKER, Geologist in Charge of Physical and Chemical Research.

T. C. CHAMBERLIN, Geologist in Charge of all Pleistocene Geology.

S. F. EMMONS, Geologist in Charge of Investigation of Metalliferous Ores.

C. WILLARD HAYES, Geologist in Charge of Investigation of Non-Metalliferous Economic Deposits.

T. W. STANTON, Paleontologist in Charge of Paleontology.

C. R. VAN HISE, Geologist in Charge of Pre-Cambrian and Metamorphic Geology.

BAILEY WILLIS (Assistant in Geology to the Director), Geologist in Charge of Areal Geology.

The field of supervision of each geologist in charge is coextensive with the work of the Geological Survey and relates to all parties engaged in work connected with his special subject. His assistance in field or office work may appropriately be

offered or invited. His opinion is to be considered authoritative in subjects under his supervision, and his approval to any report may be required. This authority, however, is restricted to the scientific aspects of the work. Administrative direction remains as heretofore wholly in the hands of the Director, and the work of the survey will proceed after the manner which has been found successful, of authorization of plans of operations after full consideration and conference upon estimates submitted by geologists in charge of parties.

Under the organization now adopted, each geologist is at liberty to make full use of the facts which he observes within his field of operations, the degree of supervision exerted by the geologist in charge of any particular subject to be duly credited in an appropriate manner. For the geologists in charge the plan affords an opportunity to study a special subject in all its aspects throughout the field of operations of the survey, either directly by personal observation or by conference with associates. This opportunity is unequaled in both multiplicity and magnitude of the phenomena presented to each specialist.

B. W.

Reviews.

Department of Geology and Natural Resources of Indiana, Twenty-fourth Annual Report. By W. S. Blatchley, State Geologist. Indianapolis, Ind., 1899.

The current report is a healthy-looking volume of 1078 pages, devoted mainly to the natural history of the state, exclusive of geology. It is well printed and bound, and but one criticism need be made of its typographical make-up, namely, that the title upon the back is not uniform in style and does not align with the titles of preceding volumes; nor they with each other, for that matter.

W. S. Blatchley (pp. 3–40) gives a brief résumé of the natural resources of the state, embodying the salient points appearing in previous reports of the department, together with such facts and statistics as have been brought in the recent work of the department.

Aug. F. Foerste (pp. 41–80) in an interesting paper discusses the synonomy and correlation of the Middle Devonian of Indiana, Kentucky, and Ohio, as embraced in the Cincinnati Anticlinal Region. The formations involved are the Madison beds (Upper Ordovician), Clinton, and Osgood Shale (Lower Niagara). The Madison beds, unfossiliferous and somewhat arenaceous, have caused much confusion, being variously classed as Clinton, Medina, and Ordovician. The various formations referred to the Medina around the flanks of the Cincinnati Anticline are to be correlated with the Madison beds. The oolitic iron-ore facies of the Clinton does not appear west of the Cincinnati axis, the Clinton being represented by a thin, salmon-colored limestone.

The author's opinions regarding the date of the Cincinnati Uplift may be quoted here in advance of the fuller conclusions promised at an early date. "The considerable variation in thickness of these limestones . . . . suggests that the Clinton lies unconformably upon the Lower Silurian, and that this unconformity could be well established if a careful study of this problem were made. The writer was, however, not able to find anything suggesting that this unconformity was in any way related to the formation of the Cincinnati axis. If the

elevation of the Cincinnati axis began in Middle Silurian this still remains to be proved. There is ample proof of local elevations in various parts of Indiana, Kentucky, and Ohio, but not of any connection between these elevations and the formation of the Cincinnati axis. . . . . The result of all my investigations for the last five years in Ohio, Kentucky, and Indiana have tended to confirm the conclusion that at the close of the Upper Silurian a considerable part of the folding which now constitutes the Cincinnati axis took place; that a period of denudation took place, removing most strata from the axis of this fold, and proportionally smaller amounts from its flanks; and that the Devonian rests unconformably upon the denuded Upper Silurian rocks upon the flanks of the axis, and that it rests upon Lower Silurian upon the middle portions of this axis."

J. A. Price (pp. 81–143, with map) outlines the distribution of the Waldron shale (Upper Niagara) through Decatur, Rush, Shelby, and Bartholomew counties, and gives numerous detailed sections covering the Devonian-Silurian parting. The name Hartsville limestone is proposed for a bed of limestone ranging up to ten feet in thickness, lying between the Waldron shale and the Devonian limestone. It is considered to be Silurian in age and as probably the equivalent of the Louisville limestone of Foerste. An interesting case of postglacial stream diversion is noted in the northwestern part of Decatur county. Flat Rock and Little Flat Rock creeks, flowing in southwesterly directions through old valleys, join near Downeyville and flow west through a narrow valley. From near the junction an old col extends to the present valley of Clifty Creek, near Milford. The glacial and preglacial course of the two branches of Flat Rock was through this old col and down Clifty Creek. Later they were diverted into the present valley of Flat Rock.

E. B. Williamson (pp. 229–333, pls. I–VII) on the Dragonflies of Indiana, gives keys for their identification, directions for collecting and preserving, and descriptions of those species known to occur in the state.

R. E. Call (pp. 335–536, pls. I–LXXVII) contributes a most complete and well-illustrated descriptive catalogue of the mollusca of Indiana, including bibliography, keys, and notes on the habits and distribution of all forms found in the state.

W. S. Blatchley (pp. 537–552) in a brief paper describes the batrachians and reptiles of Vigo county.

Stanley Coulter (pp. 553–1002) gives a comprehensive catalogue of the flowering plants, and ferns and their allies, indigenous to the state. The paper includes a bibliography and a voluminous introduction, with sections on the ecologic distribution of the plants (particularly those of the dunes), re-forestation, poisonous plants, and noxious weeds.

The reports of the state inspectors of mines, gas, and oil are also incorporated into the report. From these we learn that the production of coal for 1899 exceeded by 14 per cent. that of any preceding year, while the petroleum product shows an increase in value of 50 per cent. The average rock pressure in the natural-gas field is 155 pounds, as compared with 173 pounds in 1898, foreshadowing the early exhaustion of this popular fuel.

C. E. S.

The Geography of the Region about Devil's Lake and the Dalles of the Wisconsin, with some notes on its Surface Geology. By ROLLIN D. SALISBURY and WALLACE W. ATWOOD. Bulletin No. 5, and No. 1 of the Educational Series of the Wisconsin Geological and Natural History Survey. Published by the State. Madison, Wis., 1900.

It is seldom that a state report is readable for one who is not a geologist, or of more than local interest; but the bulletin just issued by the Wisconsin Geological and Natural History Survey is an exception. The bulletin is a volume of 151 pages with 39 plates and 47 cuts. It is one of the handsomest volumes ever issued by a state survey. The photograph is the best medium for describing nature clearly and sharply, and it has been used to good advantage throughout the report.

The report is a description of the geography and surface geology about Devil's Lake and the Dalles of the Wisconsin. Perhaps there is no region in the interior where more objects of geological interest are found in an area of a few square miles than in the territory about Devil's Lake. All the various types of topography developed by glacial action are seen in contrast with those of the driftless area, and several problems in structural geology are presented. River phenomena especially those connected with the ice invasion, are numerous. One of the best features of the book is the illustrations. The mechanical work is excellent, and each plate is typical of what it illustrates.

The book is divided into two parts: Part I describes the topography, and Part II gives the history of it development.

The quartzite ridges are the most prominent geographic features. In several places they rise to a height of 800 feet above the Wisconsin River and extend for over twenty miles in a general east-west direction. In no place is the quartzite found in horizontal beds, the dip varying between 15 and 90 degrees. Upon and against the quartzite are horizontal beds of sandstone which have been deformed but little; the sandstone topography, modified by the drift, forms the second great geographic feature of the region. It is found north and south of the quartzite ranges, and between them along the valley of the Baraboo.

The first chapter in Part II gives an outline of the history of the formations which outcrop about Baraboo. It is shown how the quartzite was changed from loose sand to quartzite and how deformation and metamorphism were developed during the uplift. The question as to the amount of erosion before the deposition of Cambrian sediments is discussed, but no definite figures can be given. The same is true as to the thickness of the quartzite. After the quartzite had been eroded for a long interval of time, geographic changes caused the sea to again cover the region and the Paleozoic strata were laid down unconformably on the eroded and folded quartzite.

Some time in the Paleozoic. perhaps at the close of the Niagara, the region was again uncovered by the sea, and the work of erosion was begun anew upon the sediments which now completely covered the quartzite bluffs.

In chapter III is given a concise treatment of rain and river erosion, adapted to the area in hand. The question of base-leveling is also discussed. Chapter IV is given over to the description of striking scenic features about Baraboo such as Devil's Lake, the Narrows, Parfrey's and Dorward's Glens, the Dalles of the Wisconsin, Natural Bridge and Castle Rock.

Chapter V deals with the glacial period and is the longest and most important in the book. The first part of the chapter is devoted to a discussion of ice, ice action, and the general results of an ice invasion. As far as possible the illustrations are taken from the region of Baraboo.

The last part of the chapter deals with the changes in drainage effected by the ice. At the time the ice was on, much of the country to the west was covered by large lakes. As the ice retreated these lakes

were drained, giving rise to many smaller bodies of water. The remnants of some of them are still in existence.

The bulletin will be useful to teachers and to geologists in general. Good use can be made of it as collateral reading in the class room. It is No. I in the Educational Series of the Wisconsin Geological Survey and is intended for use in schools. It is an innovation in state survey work and will be of great help in the teaching of geography and geology.

F. H. H. C.

A Preliminary Report on a Part of the Clays of Georgia. By GEORGE E. LADD, Assistant Geologist. Bulletin No. 6 A, Geological Survey of Georgia, 1898.

Preliminary Report on the Clays of Alabama. By HEINRICH RIES, Ph.D. Geological Survey of Alabama, Bulletin No. 6, 1900.

The volume on the clays of Georgia contains a general discussion of clays, touching their origin, composition, properties, especially those which affect their commercial value, and a discussion of the modes of handling and testing clays. A chapter is devoted to the "Fall Line" clays, on which the field work in preparation for the volume was chiefly concentrated. The results of this field work, stated in the author's language, were: "First, the tracing of the Cretaceous strata eastward, across the state, thus necessitating a modification of the geological map of Georgia, which has hitherto limited the Cretaceous to a strip of territory, traversing the central western part of the state. Second, the discovery of white kaolin, some of which ranks with the valuable South Carolina deposits as 'paper clay.' Third, the experimental proof that some of these kaolins, suitable for fire-clay, are more refractory than any of the noted fire-clays of the United States."

The clays of the state which are found to be commercially valuable are mainly in the Coastal Plain, and a sketch of the geology and physiography of this part of the state is introduced. The clay industries of the state are reviewed by localities, and some comparatives notes gathered from other states are introduced. The excellent paper and typography of the volume are to be noted as adding greatly to the attractiveness and readability of the bulletin.

The bulletin of the survey of Alabama likewise contains a general discussion of clays, touching the same general points as the discussion

opening the preceding volume. A chapter is introduced by Dr. Smith outlining the geological relations of the clays of the state. The subject is, however, incomplete, since the Tertiary and post-Tertiary clays receive little specific consideration, and it is indicated that they have not been studied in detail.

The clays of Alabama are considered with reference to their physical and chemical properties, and are discussed under the following headings: China clays, which occur in six counties; fire clays, which occur in seven counties; pottery or stoneware clays, which occur in ten counties; and brick clays, which are mentioned in eight counties. This latter class of clays must be far from complete, since the Tertiary and Pleistocene clays appropriate for brickmaking must be very widespread.

In both these bulletins the educational intent is evident for, in both cases the authors appear to have had in mind readers who have no special knowledge of geology. The idea that geological reports should be written for those who are not familiar with the technicalities of the science is fortunately one which is gaining ground, as the recent publications of many state state surveys show.

R. D. S.

THE

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THE ORIGIN OF BEACH CUSPS

IN the April-May 1900 number of this JOURNAL, p. 237, Mark S. W. Jefferson has an interesting article upon "Beach Cusps." I have often noticed these peculiar beach forms and was for some time puzzled to know how they were produced. The explanation offered by Mr. Jefferson for those on the Lynn Beach, Massachusetts, is that they "must be ascribed to the agency of the seaweed piled up on the beach, modifying the action of the greater waves." The attention I have been able to give the subject leads me to the conclusion that beach cusps are formed by the interference of two sets of waves of translation upon the beach. I know of no peculiarities of these cusps that are not explained by this theory of their origin. It will be understood by reference to the accompanying diagram, Fig. 1. The concentric lines represent two sets of waves advancing on the beach in the directions indicated by the arrows and crossing each other along the broken lines. In deep water these are waves of oscillation, but when they reach the shallow water on the beach they become waves of translation and interfere with each other where they converge upon the shore. The tendency is for them to check each other along these lines of interference and to heap up the sands at the points marked A, where they strike the beach. At the points marked B the waves diverge

and throw the beach sands and all floating material alternately right and left.

In the diagram the waves are represented as being equal distances apart, the shore has a regular curve and the cusps are

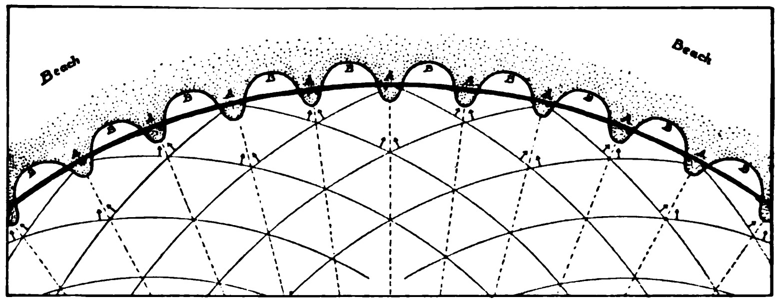


FIG. 1.—Diagram illustrating the formation of beach cusps. The concentric lines represent two sets of wave crests. The heavy line is the curve of a beach which, with these waves, would yield cusps of uniform size.

uniformly spaced. Such regularity is not to be expected in nature. The waves are not so evenly spaced, the depth of the water varies near the shore, and the waves do not all strike the shore at the same angle.

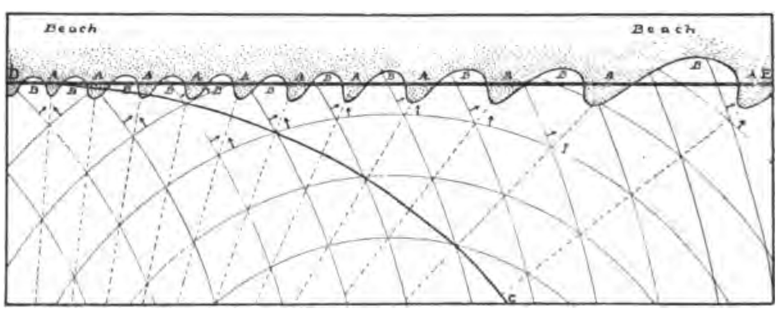


FIG. 2.—Diagram illustrating the formation of cusps of different sizes upon a straight beach D E. If D C were the beach line, these waves would produce cusps of uniform size.

In Fig. 2 the waves are represented as breaking upon a straight beach. If the water off shore were of a uniform depth and the waves were evenly spaced the cusps in this case would, for obvious reasons, be further and further apart from left to

right, as shown along the beach D E. The distance between the cusps is equal to the spaces, measured on the beach, between the radii along which the wave interference approaches the shore.

It is noticeable in California that the cusps are not permanent features of a given beach, but that they are sometimes very pronounced, at others but feebly developed, and at still others altogether obliterated or scarcely perceptible. The accompanying illustration (Fig. 3) is made from a photograph taken by the

FIG. 3.—Cusps on the beach at Santa Cruz, Cal. From a photograph taken from the Sea Beach Hotel, June 14, 1900.

writer June 14, 1900, from the Sea Beach Hotel at Santa Cruz. These particular cusps were 60, 69, 78, and 81 feet apart. They are not always visible on that beach, however. The beach of Half Moon Bay, twenty-five miles south of San Francisco, is sometimes perfectly smooth and sometimes beautifully notched. These variations are due to the changes of the relations of the waves to each other, and of the relations of the radii of the points of interference to the beach (if there are still two sets of waves). It is evident that a variation in the depth of the water off shore would retard or hasten the advance of the waves, and would consequently produce a variation in the direction of these radii and of the distance between the cusps on the beach.

On the northeast coast of Brazil I have observed cusps of remarkable height. These were, however, invariably where the water off shore was deeper and the waves broke with more than usual violence upon the beach.

I am not sure that I know how the two sets of waves referred to in this hypothesis are produced, but I am confident that they do sometimes exist, for I have seen them. It seems possible that they may be formed by an abrupt change of the wind. The concentric form is given them by their entering a bay around a headland. In one case the waves entering a broad-mouthed bay seemed to make two sets on shore by breaking around an island in the middle of the bay's mouth. It is evident that the mathematics of the work of two sets of waves might be considerably enlarged upon, but this is sufficient to call attention to the subject. That seaweeds have nothing to do with the matter is shown by the fact that at several of the places where these phenomena occur there are no seaweeds or other "drift" on the beach.

J. C. BRANNER.

STANFORD UNIVERSITY, CALIFORNIA,
August 10, 1900.

A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.[1]

BOTANISTS have long been familiar with the fact that, in some regions, aquatic plants of all, or nearly all, types are covered with a more or less copious coating of mineral matter, while in other localities the same types of plant life are free from any trace of such covering. In New England, for example, plants growing in the water are generally without such coating, while in Michigan and adjoining states it is generally present. In many lakes and streams the mineral deposit on the stems and leaves of the higher plants is very noticeable, and nearly all vegetation growing in the water is manifestly an agent of precipitation of mineral matter.

Various writers in Europe[2] and America[3] have called attention to the influence of the low types of plants growing in and around hot springs and mineral springs, on the formation of silicious sinter, calcareous tufa, and other characteristic deposits of such springs, and the connection between the beds of calcareous tufa which are sometimes formed about ordinary seepage springs whose waters carry considerable calcareous matter in solution and certain species of moss has been suggested, but so far as the writer knows, no one has given attention to the possible relation of vegetation to the more or less extensive beds of the so-called marl, found about, and in, many of the small lakes in Michigan and the adjacent states. As has been pointed out elsewhere, "Marl" is made up principally of nearly pure calcium carbonate, "carbonate of lime," with greater or less admixture of impurities. When dry and pure, it is white or

[1] Printed by permission of ALFRED C. LANE, State Geologist of Michigan.

[2] COHN: Die Algen des Karlsbader Sprudels, mit Rücksicht auf die Bildung des Sprudel Sinters: Abhandl. der Schles. Gesell., pt. 2, Nat., 1862, p. 35.

[3] WEED: Formation of Travertine and Silicious Sinter by the Vegetation of Hot Springs. U. S. Geol. Surv., IX, Ann. Rept., p. 619, 1889.

slightly cream colored, coarsely granular to finely powdery, very loosely coherent and effervescing freely in acids. On dissolving it particles of vegetable and other organic and insoluble matter are found scattered through the solution.

The ultimate source of this material, except the vegetable matter, is, undoubtedly, the clays of glacial deposits and like disintegrated rock-masses. These clays are rich in finely divided limestone and in the softer rock-forming minerals, some of which contain calcium compounds. Percolating water, containing dissolved carbon dioxide, the so-called carbonic acid gas, readily dissolves the calcium and other metallic salts up to a certain limit. The water with the dissolved matter in it runs along underground until an outlet is reached and issues in the form of a spring. This, in turn, uniting with other springs forms a stream which runs into a lake, carrying along with it the greater part of its mineral load. If the amount of carbon dioxide contained in the water is considerable, some of it will escape on reaching the surface, because of decrease of pressure, and with its escape, if the saturation point for the dissolved mineral matter has been reached, a part of this matter must be dropped in the form of a fine powder, as the water runs along over the surface. Theoretically, then, some, if not a great part of the dissolved matter, should be thrown down along the courses of the streams which connect the original outlets of the water from calcareous clays and lakes where marl occurs, and we should find the marl occurring in small deposits along these streams wherever there is slack water. Moreover, we should expect the waters of these springs and streams to show more or less milkiness on standing exposed to the normal pressure of the atmosphere at usual temperatures. Actually, however, none of these phenomena have been noted, and we infer that there is not a large amount of calcium dioxide, and not an approach to the saturation point for calcium bicarbonate, in the springs and streams feeding marly lakes.

We are then left, among others, the following alternatives, explanatory of marl formation: (1) The marl is not being

formed under existing conditions, but has been formed in some previous time when conditions were not the same as now. (2) The amount of dissolved salts is so small that the saturation point is not approached until after the lakes are reached and the slow evaporation and the reduction of the amount of dissolved carbon dioxide in the water brings about deposition of the mineral salts. (3) Some other cause, or causes, than the simple release from the water of the solvent carbon dioxide must be sought.

The first of these suggestions is met by the fact that marl is found in lakes at and below the present level of the water, and that it extends in most of them to, or even beyond, the very edge of the marshes around the lakes, and over the bottom in shallow parts of living lakes, even coating pebbles and living shells. (2) The water of lakes with swift flowing and extensive outlets, such as most of our marly lakes have, is changed so rapidly that little if any concentration of a given volume of water would occur while it was in the lake, and there is no probability that any of the lakes visited by the writer have ever been without an outlet. Indeed, many of them have outlets which occupy valleys which have been the channels of much larger streams than the present ones. Moreover, definite measurements which, however, are subject to further investigation, have been made, which show that the volume of water flowing out of these lakes is practically the same as that flowing into them, *i. e.*, the loss by evaporation is too small a factor to be taken into account. Farther, recent investigations[1] have shown that calcium, as the bicarbonate, is soluble to the extent of 238 parts in a million, in water containing no carbon dioxide. As most of our natural waters, even from living clays, contain no more than this amount of salt, even when they carry considerable free carbon dioxide, and many analyses show a less amount of it, the fact becomes plain that even if the carbon dioxide were all lost there would be no precipitation from this cause. (3) Considering these objections as valid it seems

[1] TREADWELL and REUTER: Ueber die Loeslichkeit der Bikarbonate des Calciums und Magnesiums. Zeitschrift für Anorganish-Chemie, Vol. 17, 1898, p. 170.

fitting to examine into the possibility of the plant and animal organisms living in the waters of the lakes being the agents which bring about the reduction of the soluble calcium bicarbonate to the insoluble carbonate even in waters low in the amount of dissolved mineral matter, and containing considerable carbon dioxide. That mollusks can do this is shown by the fact, which has frequently come under the writer's notice, that the relatively thick and heavy shells of species living in fresh water are often partly dissolved and deeply etched by the action of carbonic acid after the animals have, by their processes of selection, fixed the calcium carbonate in their tissues, precipitating it from water so strongly acid and so free from the salt that re-solution begins almost immediately. No natural water seems so free from calcium salts that some species of mollusks are not able to find enough of the necessary mineral matter to build their characteristic shells.

While some limited and rather small deposits of marl are possibly built up, or at least largely contributed to, by molluscan and other invertebrate shells, the deposits which are proving commercially valuable in the region under consideration, do not contain recognizable shell fragments in any preponderance, although numerous nearly entire fragile shells may be readily washed or sifted from the marl. The conditions under which marl is found are such that the grinding of shells into impalpable powder, or fine mud, by strong wave action is improbable, if not impossible, for exposed shores and shallow water of considerable extent are necessary to secure such grinding action, and these are not generally found in connection with marl.

We are, then, reduced to the alternative of considering the action of plants as precipitating agents for the calcium salts. It has been shown already that plants generally become incrusted with mineral matter in our marly lakes, and it is easy to demonstrate that the greater part of the material in the incrustation is calcium carbonate. It is also easy for a casual observer to see that the deposit is not a true secretion of the plants, for it is purely external, and is easily rubbed off the outside of the plants

in flakes, while the tissues beneath show no injury from being deprived of it, and again, as has already been pointed out, the same species of plants in some sections of the country do not have any mineral matter upon them. The deposit is formed incidentally by chemical precipitation upon the surface of the plants, probably only upon the green parts, and in performance of normal and usual processes of the plant organism.

All green plants, whether aquatic or terrestrial, take in the gas, carbon dioxide, through their leaves and stems, and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, which are easily demonstrated by any student of plant physiology, we have two possible causes for the formation of the incrustations upon plants.

If the calcium and other salts are in excess in the water, and are held in solution by carbon dioxide, then the more or less complete abstraction of the gas from the water in direct contact with plants, causes precipitation of the salts upon the parts abstracting the gas, namely, stems and leaves. But in water containing amounts of the salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates, of the oxygen set free by the plants. Of these calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:

$$CaH_2(CO_3)_2 + O = H_2O + CaCO_3 + CO_2 + O \left\{ \begin{matrix} \text{calcium} \\ \text{bicarbonate} \end{matrix} \right\} + \text{oxygen} = \text{water} + \left\{ \begin{matrix} \text{calcium} \\ \text{carbonate} \end{matrix} \right\} + \left\{ \begin{matrix} \text{carbon} \\ \text{dioxide} \end{matrix} \right\} + \text{oxygen},$$

in which the calcium bicarbonate is converted into the normal carbonate by the oxygen liberated by the plants, and both carbon dioxide and oxygen set free, the free oxygen possibly acting still farther to precipitate calcium monocarbonate.

It is probable that the plants actually do precipitate calcium carbonate, both by abstracting carbon dioxide from the water and by freeing oxygen, which in turn acts, while in the nascent state, upon the calcium salt and precipitates it, but in water containing relatively small amounts of calcium bicarbonate the latter would seem to be the probable method.

The calcium salt is deposited in minute crystals, and by the aggregation of these crystals the incrustation is formed on the plants. The crystals are distinguishable as such only for a short time on the newer growths of plants, but the incrustations are said to show a recognizable and characteristic crystalline structure when examined in thin section under a compound microscope with polarized light.

Not all aquatic plants in the same lake seem equally active in the precipitation of mineral matter. Not even all species of the same genera, even when growing side by side, will be coated equally, a fact which seems to indicate some selective metabolic processes not understood. Considering the precipitation of calcium carbonate by plants as established, even if the exact physiological and chemical processes by which this precipitation is brought about, are not yet worked out fully, it is still necessary to consider the constancy of the action and the sufficiency of the agency to produce the extensive deposits of marl which are known.

If one confines his studies simply to the seed-producing plants and other large vegetable forms which are conspicuous in lakes during the summer season, while he will find them covered with a thin coating of manifestly calcareous matter, he will at once be convinced that such work as these plants are doing is but a small factor in the total sedimentation of the lake. On the other hand, if a visit be made to a lake in early spring or late fall, all plants of the higher types will not be found, so that it becomes apparent that this agency is merely a seasonable one and works intermittently. Farther study of the plants of the same body of water, however, shows that the algæ, the less conspicuous and entirely submerged plant organism, must be taken

into account before we finally abandon plants as the agents of precipitation. Of these, two groups, differing widely in structure, habits, and method of precipitation, will be found. The first and most conspicuous, and probably the most important as well, is the Characeæ or Stoneworts. These plants are well known to botanists, and may readily be recognized by their jointed stems, which have at each joint a whorl of radiating branches, which are also jointed. In some species the stems and branches are covered with a thick coating of mineral matter, are almost white, and very brittle because of this covering. These plants not only grow near the surface in shallow water, where it is unoccupied by other plants, but in the deeper parts as well of our ponds and lakes, and, as they thrive where light is feeble, they continue to grow throughout the year, although in winter they must grow less rapidly than in summer, because ice and snow on the surface of the lakes make less favorable light conditions.

The sufficiency of these plants alone to fix and deposit calcium carbonate in large quantities is indicated by the following: In November 1899 the writer collected a large mass of plants of Chara sp?, from which five stems with a few branches were taken at random and without any particular care being taken to prevent the brittle branches from breaking off. The stems were each about 60^{cm} long, and after being dried for some days they were roughly ground in a mortar and dried for one half hour at 100° C., dried and weighed until the weight was constant. The weight of the total solid matter obtained in this way from five plants was 3.6504 grams, 0.73 grams per plant. This was treated with cold hydrochloric acid diluted, twenty parts of water to one of acid, filtered, washed, and the residue dried at 100° C., on a weighed filter paper, until weight was constant. The weight of insoluble matter was 0.5986 grams; of the total soluble matter 3.0518 grams, or .6103 grams per plant. In the lake from which the material analyzed was derived from 50 to 80 plants were counted to the square decimeter of surface in the Chara beds.

A partial quantitative analysis of material from the same source, but using stronger acid to affect solution (hydrochloric acid, diluted with four parts of water), gave the following results:

Insoluble residue	11.19 %
Iron and aluminum oxides	0.722
Calcium carbonate	76.00
Magnesium carbonate	2.359
Soluble organic matter obtained by difference	9.279

The composition of the insoluble residue was obtained by heating the residue to redness in a platinum crucible for one half hour, and the 11.19 per cent. of this matter was found to consist of:

Combustible and volatile matter	9.243 %	= 82.6 %
Mineral matter	1.947	= 17.4

The mineral matter was found to be:

Silica	1.787 %	= 92.4 %
Not determined	.160	= 7.6

Microscopic examination showed the silica to be largely composed of whole and broken tests of diatoms, minute plants which secrete silicious shells and attach themselves to the Chara stems and branches.

The mineral matter obtained in this analysis, reduced to parts per hundred, gives the following:

	Per cent.
Calcium carbonate	93.76
Magnesium carbonate	2.93
Silica and undetermined mineral matter	2.40
Iron and aluminum oxides	.89

This, with a small decrease in the mineral matter and a small amount of organic matter added, would be the composition of ordinary marls, and would be a suitable sample to consider in connection with Portland cement manufacture.

The large amount of silica may be explained by the fact that the material analyzed was collected at a season when diatoms are especially abundant.

It may be well to call attention to the fact that in many marls, especially those of large deposits, which the writer has examined

chemically, the silica has been found to be in the form of diatom shells, and hence, because of the small size and great delicacy of these structures, it is available as a source of silica for calcium silicate in cement making. If such deposits as are made up largely of diatom shells were adjacent to marl beds, it is possible they might be considered as clay and be used in cement making.

From the above considerations, it is evident that both because of the quality and quantity of its works, Chara may be considered an important agent in marl production, and it only becomes necessary to account for the chalky structure of the deposits to make the chain of evidençe complete. All algæ are plants of very simple structure, without tough or complicated tissues. Chara stems and branches are made up of aggregations of thin-walled cells, and when the plants die the cell walls must rapidly decay and the residue of lime be left. In a laboratory experiment to determine this factor, it was found that a mass of the broken-up plants placed in the bottom of a tall glass vessel filled with water became decomposed very quickly, giving the characteristic odor of decaying vegetable matter, and after a few weeks all organic matter had disappeared, leaving the incrustations in tubular, very brittle, fragments. In studying the structure of marl, the writer has found that near the top of the beds there is usually a "sandy," or even a coarsely granular structure. This is noticeable, at times, at all depths from which the samples are taken, *i. e.*, in some cases it extends through the bed. Close examination of such marl shows that this coarseness is due to the remains of the characteristic Chara incrustations, and that the "sand" and other course material is made up of easily identifiable fragments of the coatings of stems and branches of the plant. The presence of such coarse matter near the top of the beds may be considered due to sorting action of the waves, and such surface currents as may be caused in ponds and small lakes, in shallow water, by wind action. If these agents are effective in producing the coarser parts of the deposits they may be also considered so in connection with the finer parts as well, for the matter

produced by the breaking and grinding up of fragments is held in suspension for a longer or shorter time, carried about by currents, and finally sinks to the bottom in the quieter and deeper parts of the lakes.

Chara may also be looked upon as an important agent in giving the peculiar distribution to marl which has been noticed by every one who has "prospected" beds of material. The fact is frequently noticed that beds of several, and even as much as twenty or more, feet in thickness will "run out" abruptly into beds of "muck," or pure vegetable débris, of equal thickness. This distribution may show that up to a certain time conditions unfavorable to the growth of Chara are favorable to other plants obtained, until a depth of water was reached at which Chara was able to occupy the bed of muck, covering it from the bottom up, and holding the steep slope of the muck in place by mechanically binding it there by its stems and the root-like bodies by which it is connected with the mud. From the time when the Chara began its occupation of the muck the amount of organic matter left would decrease, and the amount of calcareous deposit would increase, until the latter predominated. The disturbing factors of currents and waves can be disregarded, for these abrupt unions of marl and muck are found, so far as the observations of the writer go, in most sheltered places, and not where either currents or waves could ever have operated with any force or effectiveness. Mòreover, in a lake where the marl is evidently now actively extending, the slope was observed to be nearly perpendicular, and the steep banks thus formed were thickly covered with growing Chara, to the exclusion of other large forms of plant life, and the lower parts of the growing stems were buried in mud which was mainly pure marl.

In regard to the species of Chara which seems to be the active agent in precipitation in the lakes of central Michigan, it is the form commonly known as *Chara fragilis*, but it is probable that careful study of the species throughout the range of the marl will reveal, not a single form, but a number of allied species, engaged in the same work. It may be well to suggest that

in lakes to which much silt is brought by inflowing streams, or which have exposed shores where the waves are constantly cutting and stirring up rock débris, the more slowly accumulating marls will be either so impure as to be worthless, or so obscured as to escape notice altogether, even where Chara is abundant. It may also be pointed out that shallow water, strong light, and a bottom of either clay, sand, or muck, present conditions favorable for the growth of the higher vascular plants, and that these cause such rapid accumulation of vegetable débris that the calcareous matter may be hidden by it, even when Chara is a well-marked feature of the life of a given lake.

Another plant form, like Chara an alga, but of a much lower type, which is concerned in the formation of marl is one of the filamentous blue-green algæ, determined by Dr. Julia W. Snow, of the University of Michigan, to be a species of Zonotrichia, or some closely related genus.

The work of this species is entirely different in its appearance from that of Chara, and at first glance would not be attributed to plants at all. It seems to have been nearly overlooked in this country at least by botanists and geologists alike, as but a single incidental reference to it has been found in American literature.[1] Curiously enough, however, material very similar, if not identical, to that under consideration has been described from Michigan in an English periodical devoted to Algæ.[2] In this the alga is identified as *Schizothrix fasciculata* Goment. As comparison of material is not possible at the present time, the plant under consideration is here tentatively called Zonotrichia. The plant grows in relatively long filaments, formed by cells growing end to end, and as they grow, the filaments become incased in calcareous sheaths. The feature of the plant which makes it important in this discussion, however, is its habit of growing in masses or colonies. The colony seems to start at some point of attachment, or on some object like a shell, and to grow outward radially in all directions, each filament independent

[1] McMillan: Minn. Plant Life, 1899, p. 41.

[2] G. Murray: Phycological Memoirs No. XIII, 1895, p. 1, Pl. XIX.

of all others and all precipitating calcium carbonate tubules. The tubules are strong enough to serve as points of attachment for other plants, and these add themselves to the little spheroid, and entangle particles of solid matter, which in turn are held by new growths of the lime-precipitating Zonotrichia, and thus a pebble of greater or less size is formed which to the casual observer is in no wise different from an ordinary water-rounded pebble. These algal calcareous pebbles show both radial and concentric structure and might well be taken for concretions formed by rolling some sticky substance over and over in the wet marl on which they occur but for the fact that a considerable number of them show eccentric radial arrangement, and that the shells of accretion are likewise much thicker on one side than on the other, and finally, because the side which rests on the bottom is usually imperfect and much less compact than the others. The pebbles are characteristically ellipsoidal in shape. The radial lines, noticeable in cross sections of the pebbles, are considered by the writer to be formed by the growth of the filaments, while the concentric lines probably represent periods of growth of the plants, either seasonal or annual. Included within the structure are great numbers of plants, besides the calcareous Zonotrichia, among them considerable numbers of diatoms, and it is probable that a large part of the algal flora of a given lake would be represented by individuals found in one of these pebbles. It is probable that to a certain extent they disintegrate after the plants cease to grow, for they are never very hard when wet. It is possible to recognize them, as lumps of coarser matter, even in very old marl, and the writer has identified them in marl from Cedar Lake, Montcalm county, Mich., which was taken from a bed a foot or more above, and several rods away from, the lake at its present level. From the fact that these pebbles have been found in four typical marl lakes in different parts of Michigan (in Zukey Lake, by Dr. A. C. Lane, who was struck with their peculiar character) and have been reported from a number of others by marl hunters, it is probable that they have a wide distribution in the state and are constant if not

important contributors to marl beds. It may be said in passing that the limy incrustations which are found upon twigs, branches, shells, and other objects in lakes and streams, and called generally "calcareous tufas," are of similar origin and are formed by nearly related, if not by the same, plants that form the pebbles.

Studies have been begun by the writer to solve, if possible, some of the questions which have arisen in connection with the statements embodied in this paper, but enough has already been done to show that these forms of fresh-water algæ are important lime-precipitating agents now, and to suggest the possibility that in all likelihood they have been more active in former geological times, and that, as has been suggested again and again by botanists, the formation of certain structureless limestones, and tufa deposits may have been due to their work.

CHARLES A. DAVIS.

ALMA COLLEGE,
September 1, 1900.

A REMARKABLE MARL LAKE[1]

EARLY in June 1900 the writer visited Littlefield Lake, Isabella county, Michigan, which, from its peculiar form, and the deposits about it, seemed worthy of special description.

The country about the lake is of a well-marked morainal structure, the till, however, being sandy in places, and noticeably gravelly and bowldery throughout, and formerly heavily covered with pine. The lake occupies a deep depression in a trough-like valley, surrounded by moderately high morainal hills, and from its apparent connection with a series of swampy valleys, suggests a glacial drainage valley, but as it was not followed for any distance its origin was not determined.

The lake itself is about one and one half miles long by three fourths of a mile broad in the widest part, which is near the middle of the long axis, and the shape is that of an irregular blunt-ended crescent. It was said to be over eighty feet deep in the deepest part, but no soundings were made by the writer. Its greatest length is from northwest to southeast, with the outlet at the southern end. There are no considerable streams entering it, but at least three small brooks, fed by springs from the surrounding hills, were noted flowing in, and the outlet is of such size that a boat may be easily floated on it at high water, although its level is maintained during the summer by a dam about two miles below the lake. The main inlet was not seen by the writer.

The shore lines are relatively regular, especially on the east and north sides, the convex side of the crescent, with banks twenty or more feet high close to the water on the east, while on the west side are two rather deeply indented bays. At either end are three small ponds, parasite or daughter-lakes, and surrounding the entire shore, except on the eastern side and the

[1]Printed by permission of Alfred C. Lane, State Geologist of Michigan.

northeastern or inlet end, is a cedar swamp which is underlaid by marl. The outlet is through the most southerly of the daughter-lakes, and the entire shore of the lake is formed by beautifully white marl, the exposures varying in width from a few feet to three or four rods in width, so that as one overlooks the lake from one of the surrounding hills it seems to lay in a basin of white marble.

There are three small islands in the lake, two relatively near together at the northern end, and one quite near the shore at the south end. These islands are also of marl, covered partly with a thin layer of vegetable matter and a scanty growth of grass, bushes, and cedar. There is a visible connection, under water, between at least one of the islands and the nearest shore, and it is probable that all of them are thus connected by submerged banks. The marl on the islands is from twenty-five to thirty feet deep, with sand below.

Explorations in the swampy border of the lake show that the shore was formerly more irregular than now, and that the marl extends back from the water in some places for at least one fourth of a mile, gradually becoming more and more shallow until the solid gravel or clay is reached. The marl is frequently thirty feet deep along the shore, and at no place was it found to be less than fifteen feet deep at the present shore line, the shallowest places being along the shore where the high bank comes down near the water. The deepest vegetable deposit, or peat, found in one hundred and fifty borings in all parts of the deposit was three feet. The main deposits of marl are about the southeast end and along the western side of the lake, with a body of considerable size underlying a swampy area at the north end. Of the six daughter-lakes four are very small, an acre or two in extent, and entirely surrounded by deep marl, the connection between three of them and the mother-lake being shallow and narrow, a few inches deep, and a few feet wide, and only existing at high water, while two of the other three are of much larger size, with marl points extending out from either side of the strait, which is still relatively wide and deep.

Of the two bays on the west side of the lake, one is much narrower than the other, and at the mouths of both, marl points are extending towards each other to a noticeable degree.

At all points along the shore the slope of the marl is very abrupt from the shallow water to the bottom, always more than 45°, and frequently nearly 90°, this steepness being noticable in the small as well as in the parent lakes, while on the east side of the island at the south end of the lake, the wall of marl seemed positively to overhang, although this appêarance was probably due to refraction.

The texture of the deepest part of this marl deposit is apparently that of soft putty; a sounding rod passed through it with comparative ease, and samples brought up have a yellowish or creamy color, which disappears as they dry, leaving the color almost pure white. At the surface the marl is coarser, slightly yellowish, and more compact. Where it lies above the water line it is distinctly made up of granular and irregular angular fragments, resembling coarse sand, but the fragments are very brittle, soft, and friable, and may be converted into powder by rubbing between the thumb and fingers.

On the parts of the shores where apparently the wave action is chiefly exerted, there are small rounded calcareous pebbles, mixed with molluscan shells, drift material, and considerable quantities of stems, branches, and more or less broken fragments of the alga Chara, all parts of which are heavily incrusted with calcareous matter. This Chara material was often piled up in windrows of considerable extent at the high-water mark.

The marl banks of the lake, from a little below the water's edge down as far as could be seen, were generally thickly covered with growing Chara. At the time of the writer's visit, and wherever a plant of it was examined, it had a heavy coating of limy matter, which was so closely adherent to the plant as to seem a part of it, and because of this covering the plants were inconspicuous and would easily escape notice.

Little if any other vegetation of any character was growing in the lakes at this season; indeed, from the steep slope of the

banks of marl, it would be hardly possible for any considerable amount of vegetation of higher types than algæ to flourish here, because of the lack of light at the depth at which it would have to grow to establish itself.

As Chara of several species is known to occur within our limits at depths as great as thirty feet, and probably grows at even greater depths where the water is clear and the bottom soil is of the right character, *i. e.*, of clay, finely divided alluvial matter, marl, etc., it is apparent that there must be an immense growth of this type of plants in such a lake as the one under discussion. That there is an abundance of Chara in Littlefield Lake is shown by the amount of drift material, composed of the plant, which has accumulated in heaps at the high-water wave marks along the shore at various places.

From even a casual inspection of this drift accumulation, it is evident that it is the source of much of the granular and sand-like marl on the beaches and in the coarse upper layers of the deposit. This wind-and-wave accumulated material was dry and bleached, and was very brittle—so fragile, indeed, that a mere touch was generally sufficient to break it into fragments, and it passed by insensible gradation from the perfect, unbroken, dried plant form at the high-water mark, in which every detail, even the fruit, is preserved, to inpalpable powder at and below the water's edge.

In other words, we have in Chara, a plant of relatively simple organization, able to grow in abundance under most conditions of light and soil which are unfavorable to more highly developed types, a chief agent in gathering and rendering insoluble calcium and other mineral salts brought into the lake from the clays of the moraine around it by the stream, spring, and seepage waters. After precipitation is accomplished and the plant is dislodged or dies it drifts ashore, where, after the decomposition and drying out of the small amount of vegetable matter, the various erosive agents at work along shore break up the incrusting chalky matter, and the finer fragments are carried into deeper water, the coarser are left along the lines of wave action.

The pebbles mentioned above as occurring on parts of the shore are also the result of the development and growth of an alga, Zonotrichia or a nearly related genus, a much lower type than Chara, having a filamentous form. The vegetable origin of these pebbles would not be suspected until one recently taken from the water is broken open, when it is found to show a radiating structure of bluish-green lines, the color indicating the presence of the plants, as it is characteristic of the group to which Zonotrichia belongs.

The relation of the deposits about Littlefield Lake to the direction of the prevailing strong winds of the region is probably significant.

The area of deposition is at the southeast end and along the whole western side of the lake. The winds which would be most effective in the valley of the lake would be those from the north and northwest, which would drive the surface waters down the lake toward the southern end, and, striking the shore on the eastern side, these currents would be turned across the lake to the west, depositing sediment at the turning area and in slack water beyond. The daughter-lakes are not easily accounted for except in a general sense, that they were formerly deep bays, which, by the building out of points of marl on either side of their mouths, were finally enclosed. The tendency, already noted, for existing bays to have points of marl of spitlike form extend from either side of the mouth would seem to indicate this as a probable method of formation. On the island at the south end of the lake there was manifestly a strong current, which was running southeasterly and depositing fine marl on the east side of the island, the wind, at the time the observation was made, blowing gently from a few points north of west.

As has been already noted, the islands consist of marl from twenty-five to thirty feet deep, the bottom on which they are built up being, to judge from soundings made with an iron rod, of rather fine sand. These foundations of sand have deeper water all around them, if soundings said to have been made by local fishermen can be relied upon; so it is possible they

represent shallows in the original lake bottom, upon which, after Chara had established itself, the marl accumulated, both by direct growth of the plants and by sedimentation. It may be worthy of mention that the Chara growing on the steep banks may, in part, account for their steepness by acting as holding agents, binding the particles of sediment in place by stems and the rootlike organs which the plant sends into the mud. It is probable that but a small part of the Chara that grow in the lake ever reaches the shore wave-line, and much must break up by the purely chemical processes resulting from organic decay in relatively deep water.

CHARLES A. DAVIS.

THE ORIGIN OF THE DÉBRIS-COVERED MESAS OF BOULDER, COLORADO

At the base of the mountains south of Boulder, Colorado, is found a series of table lands, or mesas, which rise 300 to 500 feet above the bed of Boulder Creek, and which slope away from the mountains at an angle of about $3\frac{1}{2}°$. Mesas of a similar nature are found at numerous points along the mountain front, some of them much more extensive than the ones of which I write. This article is the result of a study of those included between Boulder Creek and South Boulder Creek. Their location is shown in Fig. 1. A photograph (Fig. 2) shows their general aspect and their relation to the foothills. Fig. 3 is an east-west section of the mesa shown in the photograph, giving its structure. A sheet of unconsolidated fragmental material, 25 to 50 feet in thickness, rests upon the eroded surface of the upturned Cretaceous formations, principally the Fort Pierre shale. The Benton, Niobrara, and Dakota are inconspicuous at this point, owing to the proximity of the Boulder arch described by Eldridge.[1] This covering of débris forms the protecting cap of the mesas. It is composed almost wholly of sandstone and conglomerate from the Red Beds of Permo-Trias age, which formerly covered the mountain front and which still rise about 2000 feet above the level of the plains. Their serrate peaks are shown along the lower mountain front in Fig. 2. At this point the Red Beds dip at an angle of 48°. The fragments of the detrital capping vary in size from grains of sand to bowlders twenty feet in diameter. They are notably angular, bearing little evidence of long continued water action, and are very imperfectly sorted. Coarse and fine materials are bedded together in the most intimate relations. Originally they formed a continuous sheet of débris, the greater part of which has been destroyed by subsequent erosion.

[1] U. S. Geol. Surv., Mon. 27, p. 105.

The mesas are bordered by rather sharp declivities. Between the foot of these declivities and the flood plains of the creeks is an inclined surface which may be called the mesa-terrace. It is a wide shelf-like surface extending from the base of the mesas

FIG. 1.—The geological formations in order from the left (west) are: (1) Crystallines of the Mountains; (2) Lower Red Beds; (3) Upper Red Beds; (4) Como (Atlantosaurus Beds); (5) Dakota; (6) Benton; (7) Niobrara; (8) Ft. Pierre and Fox Hills; (9) Laramie.

proper to the border of the present flood plains, where in some cases it is terminated by a bluff, while in others it descends in a gentle transition slope not always separable from the mesa-terrace, making one continuous incline from the base of the mesas to the border of the flood plain, into which it passes by imperceptible gradations. Where this transition slope has been

destroyed by the existing streams, and a bluff or steep slope formed, the mesa-terrace impresses one as being possibly due to a former cycle of erosion. But where the transition slope is intact and the surface of the mesa-terrace passes gently into that of the flood plain the two are seen to be obviously due to a continuous process of erosion uninterrupted by any notable change in the attitude of the land.

The substructure of the mesa-terrace is similar to that of the mesas proper, but its surface is more irregular and the covering of fragmental material is not uniform in thickness or in distribution. The mesa-terrace is shown, in part, in the middle foreground of Fig. 2 with the buildings resting upon its surface. The covering of the mesa-terrace differs from that of the mesas, first, in the thinner and more irregular nature of the sheet of débris; second, in the more rounded character of the fragments; and third, in the greater content of crystalline material. The débris on the tops of the mesas contains about 1 per cent. of crystalline material, while the débris on the mesa-terrace is made up of sandstone and crystalline material in varying proportions. The crystalline material of the mesas is chiefly quartz and metamorphic sandstone, such as is contained in the conglomerate of the Red Beds, from which it very probably came, in the main. The crystalline material on the mesa-terrace is largely granitic, and is usually much water-worn and in an advanced stage of decomposition.

At still lower levels is found the sheet of débris which is now gathering over the valley bottoms of the existing streams. These streams are forming wide bottom lands[1] which have a gradient at Boulder of about fifty feet to the mile. In this recent débris the material is imperfectly sorted and is composed largely of crystalline rock from the mountains. The fragments are well rounded and the granitic constituents are not usually decomposed.

In these three stages we find an instructive series; first, the mesa tops, composed mainly of sandstone débris of an angular, slightly worn character; second, on the mesa-terrace the mantle

[1] See Pocket Map, Mon. 27, U. S. Geol. Surv.

FIG. 2.—Photograph of the region south of Boulder, from a point north of the city. The surface of one of the mesas and the mesa-terrace appears in the horizon at the left. The point at the extreme right is the peak of Green Mountain, and that in the background is South Boulder Peak.

has proportionately less sandstone, more metamorphic, and more granitic material, the latter in a much decomposed state; and third, the recent valley drift, composed mainly of well rounded crystalline material of which undecomposed granitic rock forms a large part.

There is one other group of phenomena which must be considered before attempting an interpretation. There is a large mesa near the mouth of Bear Canyon (see map, Fig. 1) on which the largest bowlders are found in great numbers. This mesa is also the highest in the region under discussion. A line drawn from its top, parallel to the foothills and touching the tops of the mesas to the north, would have a gentle slope in that direction, *i. e.*, toward Boulder Creek. A similar though indistinct slope toward South Boulder Creek is indicated by

some remnants south of this mesa. The mesa-terrace has a corresponding inclination.

From the foregoing facts the conditions of formation may be inferred :

1. At the time the mountains began to assume their present elevation they were faced, if not covered, with the sedimentary formations whose truncated edges are now exposed along the foothills. At an early stage of erosion the young streams carried away the shales, since they lay uppermost, and formed the grade upon which the sandstone débris was deposited. The streams found little of a coarse or enduring nature with which to form a deposit and thus prevent the cutting down of the shales to a low gradient until they had cut back into the Red Beds.

2. When the erosion began to work effectively upon these, much coarse and enduring material was loosened and carried down the high gradient of the mountain flank, but the streams were unable to carry all of the coarse parts of it across the lowered gradient of the shale tract, and hence deposited it as the mantle of the present mesa tops.

3. As the streams by headward extension reached back into the crystalline area, they derived a less relative amount of material from the Red Beds and more from the crystalline area. Besides, by reaching backward, their gradients had been reduced and they reacquired some eroding power in the mesa zone, and hence cut into it and formed the lower surface — the mesa-terrace — on which is found relatively more crystalline material and relatively less of that from the Red Beds. The granitic material of this mantle being relatively old is much decomposed.

4. The later deposits represent the process carried farther, giving a still larger proportion of crystalline débris, and this, being young, is undecomposed.

At first Bear Creek was an important stream, as shown by the wide gap between Green Mountain and South Boulder Peak. But, for reasons unexplained, Boulder Creek and South Boulder Creek, on either hand, gained in importance at its expense, and

as they more effectually lowered their channels a new grade was produced in the mesa zone, represented now by the mesa-terrace. At the same time this new grade was covered with material formed by a mingling of the old mesa-tops débris with the fresher material from the mountains.

The process of forming the grade and covering it with débris in this manner may be studied in minutest detail at the present day in Boulder Creek Valley. As the present streams are cutting away the mesa-terrace and mingling its fragmental material with

Section of formations shown in FIG. 2.

FIG. 3.

E—Fragmental débris. B—Red Beds.
D—Fort Pierre Shale. A—Crystallines.
C—Dakota.

the fresh material from the mountains, so the more ancient streams undermined the sheet of débris on the mesa-tops and mingled it with that of the then flood plains.

The production of the abrupt slopes forming the sides of the mesas, and to a less extent bounding the mesa-terrace on the one hand, and on the other hand the lateral inclination of the surfaces of both, is well illustrated in Boulder Creek Valley. Before issuing from the crystalline area Boulder Creek has a high gradient and little of its energy is spent in cutting sidewise. Where it passes to the shale formations at Boulder, its gradient becomes lower and much of its energy is spent in cutting laterally. The result is a comparatively slow lowering of the bed of the stream and a comparatively swift migration laterally in the shale region. The migration is at present toward the south. The city

of Boulder is built upon the ground recently abandoned by the stream. A north-south section through the city (see map, Fig. 1), cutting directly across this recently formed grade, shows a slope of the surface to the south of nearly fifty feet to the mile. The tops of the mesas and the surface of the mesa-terrace have an inclination somewhat greater than this but in the opposite direction. It is near the city of Boulder that the most conspicuous slopes are found bordering the mesa-terrace. The transition slope has been cut away and bluffs formed fifty feet high in

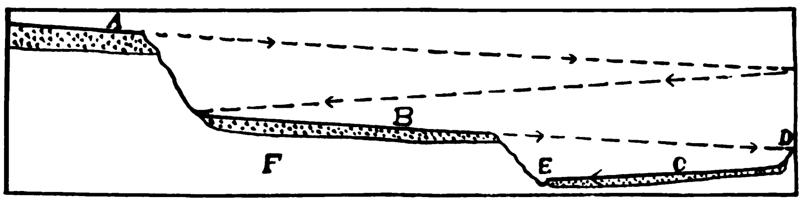


FIG. 4.—Diagrammatic section from the mesa (*A*) south of Boulder City, to the northern border of the present valley bottom, illustrating the assigned origin of the lateral inclinations of the mesa tops, mesa-terrace and valley bottom. *A*=mesa; *B*=mesa-terrace; *C*=valley bottom on which the city stands; *E*=Boulder Creek; *F*=Fort Pierre shale. The dotted lines represent the migrations of Boulder Creek together with the gradual lowering of its bed, the two processes combined producing the northward inclination of the mesa tops and the mesa-terrace, and the southward inclination of the valley bottom.

places. Should this process be continued to the extent of reducing the mesa-terrace to the lateral proportions of the mesas, the transition slopes would all disappear, and the bounding slopes of the mesa-terrace would present essentially the same aspect as those of the mesas. The probable action of the stream in producing the northern inclinations of the mesa-tops and the mesa-terrace together with their bounding slopes, and the southern inclination of the valley bottom by means of lateral migrations is illustrated in Fig. 4.

It is quite impossible to say what influence, if any, surface movement has had in changing the inclinations of the surfaces or determining special features. It seems, however, unnecessary to appeal to such movement, since the phenomena may be

rationally explained by such processes of erosion and deposition as may be witnessed in the same region at the present time.

Conclusions.— From the phenomena observed in this region four conclusions may be drawn: (1) That the accumulations of débris forming the protecting surface of the mesas and the mesa-terrace are of fluviatile origin, and that in their mode of accumulation they differ in no essential respect from that in action over the valley bottoms in that vicinity at the present day. (2) That the mesa tops mark the level of a grade formed by the young streams soon after the adjacent mountains had assumed something like their present attitude. (3) That the three grades represented by (*a*) the mesa tops, (*b*) the mesa-terrace, and (*c*) the present valley bottoms do not seem necessarily to require the assumption of any change in the attitude of the land subsequent to the elevation of the mountains, but are the natural sequences of erosion as influenced by the local distribution and difference in hardness of the formations involved. (4) That the grades were formed and covered with débris by the streams at essentially the same time, and that it is contrary to the observed phenomena to assume that the grading was done at one period and the débris accumulated during some other period.

WILLIS T. LEE.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE[1]

CLEMENTS, SMYTH, BAILEY, and VAN HISE[2] describe the Crystal Falls iron-bearing district of Michigan.

The rocks of the district comprise two groups, separated by unconformities. These are the Archean and the Algonkian. The Algonkian includes both the Lower Huronian and the Upper Huronian series, and these are also separated by unconformities. The terms Lower Huronian and Upper Huronian are applied to the series which occur in this district because they are believed to belong to the same geological province as the Huronian rocks of the north shore of Lake Huron, and to be equivalent to the Lower Huronian and Upper Huronian series which there occur.

The Archean is believed to be wholly an igneous group, and therefore no estimate of its thickness can be given. It covers a broad area in the eastern part of the district, and from this several arms project west. West of the main area there are two large oval areas of Archean.

The Lower Huronian series, from the base upward, comprises the Sturgeon quartzite, from 100 feet to more than 1000 feet thick; the Randville dolomite, from 500 to 1500 feet thick; the Mansfield slate, from 100 to 1900 feet thick; the Hemlock volcanic formation, from 1000 to 10,000 or more feet thick; and the Groveland formation, about 500 feet thick. A minimum thickness for the series is about 2200 feet, and a possible maximum thickness is more than 16,000 feet. However, in the latter case, a large part of the series is composed of volcanic material. It is not likely that the sediments at any one place are as much as 5000 feet thick.

The Upper Huronian is a great slate and schist series, which it is not possible to separate on the maps into individual formations. It is impossible to give even an approximate estimate of the thickness of this series.

[1] Continued from page 443, Vol. VIII, JOUR. GEOL.

[2] The Crystal Falls Iron-bearing District of Michigan, by J. MORGAN CLEMENTS and H. L. SMYTH, with a chapter on the Sturgeon River Tongue, by W. S. BAYLEY, and an Introduction by C. R. VAN HISE: Mon. U. S. Geol. Surv., No. XXXVI, 1899. With geological maps.

Various igneous rocks intrude in an intricate manner both are Upper Huronian and the Lower Huronian series.

In the following paragraphs the descriptions of the formations we summarized somewhat more in detail.

The Archean.— The Archean consists mainly of massive and schistose granites and of gneisses. Nowhere in the Archean have any rocks of sedimentary origin been discovered. The Archean has been cut by various igneous rocks, both basic and acid, at different epochs. These occur in the form both of bosses and of dikes, the latter sometimes cutting, but more ordinarily showing a parallelism to, the foliation of the schistose granites. The granites must have formed far below the surface, and therefore must have been deeply denuded before the transgression of the Lower Huronian sea. The Archean granites and gneisses and the earlier intrusives alike have been profoundly metamorphosed, and at various places have been completely recrystallized.

The Lower Huronian series.—The Sturgeon quartzite, the first deposit of the advancing sea, when formed consisted mainly of sandstone, but in places at the base it consisted of coarse conglomerate. The conglomerate is best seen in the Sturgeon River tongue. Elsewhere evidence of conglomeratic character at the base of the formation is seen, but the metamorphism has been so great as nearly to destroy the pebbles. However, in the Sturgeon River tongue is a great schistose conglomerate, which, while profoundly metamorphosed, still gives evidence of the derivation of its material from the older Archean rocks. The sandstone has been changed to a vitreous, largely recrystallized quartzite, which now shows only here and there vague evidence of its clastic character.

The Sturgeon formation varies from probably more than 1000 feet in thickness in the Sturgeon River tongue to less than 100 feet in thickness at places in the Felch Mountain range, and is altogether absent in the northeastern part of the district.

In the southeastern part of the district the Sturgeon quartzite is overlain by the Randville dolomite. In the central part of the district the quartzite between the Archean and the Randville is so thin that it cannot be represented on the maps as a separate formation. In the northeastern part of the district a quartzite, resting on the Archean, but occupying a higher position stratigraphically than the Randville dolomite, is overlain by an iron-bearing formation. It appears,

therefore, that the Sturgeon sea gradually overrode the district, and that at the time the Sturgeon quartzite was deposited in the southeastern part of the area the Archean was not yet submerged in the central and northeastern parts of the district. However, since the quartzite resting on the Archean in the latter area cannot be separated lithologically from the Sturgeon quartzite, both are given the same formation color, but the later quartzite is given a separate letter symbol. The quartzite color therefore represents the transgression deposit of the same general lithological character, rather than a formation all parts of which have exactly the same age. While nowhere in the district is there any marked discordance between the schistosity of the Archean and the Sturgeon quartzite, the conglomerates at the base of the latter formation in the Sturgeon River tongue are believed to indicate a great unconformity between the Archean and the Lower Huronian series. The change from the Sturgeon deposits to those of the Randville was a transition.

The Randville dolomite is a nonclastic sediment, and is believed to mark a period of subsidence and transgression of the sea to the northeast, resulting in deeper water for much of the district. Since the Randville dolomite has its full thickness on the Fence River just east of the western Archean oval, and does not appear at all about the Archean oval a short distance to the northeast, it is probable that the shore line, during Randville time, was between these two areas and that the land arose somewhat abruptly toward the northeast. As the Randville formation has a thickness of 1500 feet, it probably represents a considerable part of Lower Huronian time.

Following the deposition of the Randville dolomite, deposits of very different character occur in different parts of the district. These deposits are: (1) The Mansfield formation, (2) the Hemlock volcanic formation, and (3) the Groveland formation.

The Mansfield formation was a mudstone, which has subsequently been transformed into a slate or schist. The Hemlock formation is mainly a great volcanic mass, including both basic and acid rocks, lavas, and tuffs, but it contains also subordinate interbedded sedimentary rocks. This formation occupies a larger area than other of Lower Huronian formation, and is perhaps the most characteristic features of the Crystal Falls district. The Groveland is the iron-bearing formation. It includes sideritic rocks, cherts, jaspilites, iron ores, and other varieties characteristic of the iron-bearing formations

of the Lake Superior region. In all important respects these rocks are similar to those of the Negaunee formation of the Marquette district, with the exception that in the southeastern part of the Crystal Falls district, associated with the nonclastic material, there is a considerable proportion of clastic deposits. The Groveland formation contains iron carbonate and possibly glauconite, from which its other characteristic rocks were derived.

The variability in the character of the deposits overlying the Randville formation is probably caused by the great volcanic outbreaks in the western part of the district. In the southern and southeastern parts of the area the deposit overlying the Randville formation is the Mansfield slate and schist. North of Michigamme Mountain and of the Mansfield area the Mansfield formation is replaced along the strike by the Hemlock volcanic formation, which directly overlies the limestone for most of the way about the western Archean oval. The effect of the volcanic outbreak apparently did not reach so far as the northeastern part of the district.

Overlying the Mansfield formation in the southeastern part of the district and the Randville formation in the central part of the district is the Groveland iron-bearing formation. In the Mansfield slate area the iron-bearing rocks appear near the top of the Mansfield formation intercalated with the slates. The Groveland formation cannot be certainly traced farther north than the northeastern portion of the western Archean oval. It is apparently replaced along the strike by the Hemlock volcanics.

In the northeastern part of the district the Groveland formation, equivalent to the Negaunee formation of the Marquette district of Michigan, is found above the Ajibik formation. The occupation, in the western part of the district, by the Hemlock volcanics of the same part of the geological column as occupied by the Hemlock volcanics east of the western Archean oval, the Mansfield slate, and the Groveland formation, is explained by the fact that in the western part of the district the volcanoes broke out and there continued their activity longest. While north of Crystal Falls the volcanic rocks were laid down, the Mansfield formation was being deposited in the southeastern part of the district. This activity continued there through the time in which the Groveland formation was being deposited in other parts of the district.

From the foregoing it appears that the Hemlock formation in the western part of the district is equivalent:

1. East of the western Archean oval, to the Hemlock volcanics found there and the overlying Groveland formation.

2. At Michigamme Mountain, to the Mansfield slates and the Groveland formation.

3. In the Mansfield area, to the Mansfield slates and the Hemlock volcanics occurring there.

4. In the southeastern part of the district, to the Mansfield and Groveland formations.

The replacement of an iron-bearing formation by the great volcanic formation just described is exactly paralleled in the Upper Huronian rocks of the Penokee iron-bearing series, where the pure iron-bearing formation is replaced at the east end of the district by a great volume of volcanic rocks intercalated with slates and containing bunches of iron-formation material.

Following the deposition of the Lower Huronian series, the region was raised above the sea and eroded to different depths in different places. In the Felch Mountain range the only formations above the Randville dolomite are a thin bed of slate and the Groveland iron formation. In the northeastern part of the district only a thin belt of iron-formation rocks remains. In the central and western parts of the district there is a great thickness of volcanics. This, however, does not imply a difference of erosion equal to the difference in thickness of these rocks, for doubtless when the volcanics were built up there was contemporaneous subsidence, so that at the end of Lower Huronian time there may have been little variation in the elevation of the upper surface of the series, but very great differences in its thickness.

The Upper Huronian.—After the Lower Huronian series was deposited the district was raised above the sea, may have been greatly folded, and was eroded to different depths in different parts of the district.

Following the earth movements and erosion, the waters for some reason advanced over the district, and the Upper Huronian series was deposited. The basal horizon was a conglomerate, which has, however, very different characters in different parts of the district.

In the eastern half were Archean rocks, the Sturgeon quartzite, the Mansfield slate, and the Groveland iron formation. Upon these was deposited a sandstone which locally was very ferruginous. This has

subsequently been changed iuto a ferruginous quartzite. The typical occurrence of this quartzite is at the end of the Felch Mountain range. It also appears between the Archean ovals in the northeastern part of the district. If distinct conglomerates were formed at the bottom of this quartzite, they are buried under glacial deposits or have disappeared as the result of metamorphism.

In the western part of the district the rocks of the Lower Huronian at the surface are the great Hemlock formation, and here the basal horizon of the Upper Huronian is a slate or slaty conglomerate, the fragments of which are derived mainly from the underlying Hemlock formation. The sandstones and conglomerates varied upward into shales and grits, which have been subsequently altered into mica-slates and mica schists. After a considerable thickness of mudstone and grit was deposited, there followed a layer of combined clastic and non-clastic sediments, the latter-including iron-bearing carbonates. These appear to be at a somewhat persistent horizon, and in this belt are found the iron-formation rocks, and iron ores in the Upper Huronian in the vicinity of Crystal Falls. Above these ferruginous rocks there was deposited a great thickness of shales and grits which have been transformed into mica-slates and mica-schists.

Since the deposition of the Upper Huronian the rocks of the district have been folded. The more complex folds vary from a north-south to an east-west direction. The closer folds in the northeastern part of the area are nearly north-south. In the central part of the area the closer folds strike northwest-southeast. In the eastern and southeastern parts of the district the closer folds are nearly east-west. All of these folds have steep pitches.

Subsequent to, or during the late stage of, this time of folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan. At this time there were introduced into both the Lower and Upper Huronian vast bosses and numerous dikes. The intrusives vary from those of an ultrabasic character, such as peridotites, through those of a basic character, such as gabbros and dolorites, to those of an acid character, such as granites. These intrusives, while altered metasomatically, do not show marked evidence of dynamic metamorphism; therefore the conclusion that they were introduced later than the period of intense folding already described.

Cambrian rocks overlie unconformably the rocks above described.

DESCENDING SUCCESSION OF FORMATIONS IN THE MARQUETTE, CRYSTAL FALLS, AND MENOMINEE DISTRICTS.

MARQUETTE DISTRICT	CRYSTAL FALLS DISTRICT	MENOMINEE DISTRICT
UPPER MARQUETTE	UPPER HURONIAN	UPPER MENOMINEE
1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the district by the Clarksburg volcanic formation.	1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon.	1. Great Slate formation.
2. Ishpeming formation, being composed of the Goodrich quartzite in the eastern part of the district, and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	2. Quartzite in eastern part of the district.	
Unconformity	Unconformity	Unconformity
LOWER MARQUETTE	LOWER HURONIAN	LOWER MENOMINEE
1. Negaunee iron formation, 1000 to 1500 feet.	1. The Groveland formation, about 500 feet thick.	1. Vulcan iron formation containing slates.
2. Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick.	2. Hemlock volcanic formation, 1000 to 10,000 feet thick. In western part of district also occupies place of (1) and (3).	2. Antoine dolomite.
3. Ajibik quartzite, 700 to 900 feet.		
4. Wewe slate, 550 to 1050 feet.	3. Mansfield formation, 100 to 1900 feet thick.	
5. Kona dolomite, 550 to 1375 feet.	4. Randville dolomite, 500 to 1500 feet thick.	
6. Mesnard quartzite, 100 to 670 feet.	5. Sturgeon quartzite, 100 to 1000 feet thick.	3. Sturgeon quartzite.
Unconformity	Unconformity	Unconformity
ARCHEAN	ARCHEAN	ARCHEAN

Lane[1] gives a detailed account of the geology and petrography of Isle Royale, Lake Superior. The island trends north of east and the edges of the strata outcrop in approximately this direction. The rocks are interbedded conglomerates, sandstones, and traps of Keweenawan age, dipping in a southerly direction at angles varying from 8–32°, the higher dips in general to the north. Faults are shown to exist at various places with directions approximately northeast–southwest and northwest–southeast, and the probable existence of other more extensive faults running entirely across the island is indicated. The detailed sections with correlations with the Keweenawan of other parts of Lake Superior are given in table on page 520.

Hubbard[2] discusses the geology of Keweenaw Point with particular reference to the felsites and their associated rocks. The term felsite is used to include all the very fine-grained and highly acid igneous rocks. These occur at a number of horizons below the Bohemian conglomerate, so-called from the fact that it skirts the northern side of this range near the northeastern end of Keweenaw Point. The outcrops of felsite studied occur in Sec. 30, T. 58, R. 27 (New England or Keystone location); Sec. 25 (?), Sec. 35 (Fish Cove), Secs. 26 and 27 (Little Montreal River), all in T. 58, R. 28; Secs. 29 and 30, T. 58, R. 28 (Bare Hill and westward therefrom) Secs. 23 and 24, T. 58, R 29 (Mt. Houghton) and both eastward and westward therefrom; Sec. 10, T. 57, R. 31 (Suffolk location, Praysville); Sec. 4, T. 56, R. 32 (Allouez Gap, east of the Kearsage and Wolverine mines); Sec. 30, T. 56, R. 32 (falls on branch of Trap Rock River); Sec. 36, T. 56, R. 33 (Douglass Houghton Falls), and Sec. 1, T. 55, R. 33 (Hecla and Torch Lake R. R).

The evidence concerning the source of the Keweenawan lavas is considered and it is concluded that they may probably have come from a higher level somewhat back from the edges of the present Keweenawan basin.

With this probability in mind, the following hypotheses are suggested:

1. The irregularities in the lower beds of the Keweenaw series in the Portage Lake area, contrasted with the greater regularity of the

[1] Geological Report on Isle Royale, Michigan, by A. C. LANE: Geol. Surv. of Mich., Vol. VI, 1898, Pt. 1, pp. 1–281. With geological map.

[2] Keweenaw Point with Particular Reference to the Felsites and their Associated Rocks, by L. L. HUBBARD: Geol. Surv. of Michigan, Vol. VI, 1893–1897, Pt. 2, pp. 184. With plates.

Name		Depth in drill hole, feet	Total thickness from o feet	Number in Eagle River section	Thickness in Eagle River Section	Copper Falls section	Tamarack section	Conglomerate numbers	Distances	Minnesota correlations
Upper sandstone and conglomerate		....	2600	2500	....	....	....	....	....	....
First known trap	Marvine's (c)	0	0	No. 1	....	....	....	....	....	
Ophites, numerous sandstones	Marvine's (c)	....	....	....	....	....	....	....	....	
Island mine conglomerates	Marvine's (c)	170	567	35	1146	1035	2146	18 ?	....	
Transition flows, porphyrite and ophite	Marvine's (c)	193	589			1012				
		415	806							
Scoriaceous conglomerate	Marvine's (b)	426	817	44	1417	745	2021	17	....	Temperance River group ?
Green porphyrites	Marvine's (b)	279	1100	63	1810	368	1639	17	853	
Scoriaceous conglomerate "Ashbed"	Marvine's (b)	291	1112	65	....	....	....		885	
		....	....	....	2035	160	....	....	....	
Porphyrites	Marvine's (c)	....	....		....	0	....	....	....	
Red sandstone	Marvine's (c)	377	1526	80 ?	2432	495	1081	16	1435	
Porphyrites, etc	Marvine's (c)	419	1567		2496	500	1053		1445	
Felsite tuff	Marvine's (c)	81	2035	....	....	....	160	*	....	
		91	2045	....	....	....	....	....	....	
Ophite, and the thickest ophite—the Green-		....	....	90.	2840	Central	....	....	....	Beaver Bay group ?
stone Conglomerates — the Allouez or		....	....	108	4120	mine	....	....	....	
"Slide"		363	2310	....	....	0	0	15	2345	
		386	2332	....	....				2378	
Amygdaloids mainly and thin ophites		136	2570 ?	....	....	660	....	14	....	Agate River group ?
		175	....	....	....	....	....			
		133	3197	....	....	1474	1309	13	....	
		....	....	....	....	....	....	12	....	
Minong { breccia		386	4030						4853	
Minong { porphyrite		426	4068	"Kings	ton" or					
Minong { trap		456	4097	Kear	sarge ?	2599	2239	11	4873	
		536	4174							
Various beds ending with a thick ophite		....	....	....	....	....	....	....	....	
Huginnin porphyrite		367	5194							
		436	5260							
Ophites										
Felsitic conglomerate		475	5868					6	7643	
		487	5879							
Various igneous flows and conglomerates		....	....	....	....	....	....	....	....	
Felsitic conglomerate and felsite tuff		786	6155							
		910	6267							
Felsite		....	6400	Prays	ville	....	....	....	....	

* 67.7 above Allouez at Peninsula mine.

higher part of the series, suggest that in this area, near the contact between the Keweenaw series and the Eastern sandstone, we are on the edge of an early-Keweenawan or pre-Keweenawan basin.

2. If the lower beds of the Keweenaw series near Portage Lake rested on the sides of a basin, the later beds of the series from here eastward lay at a higher altitude and, excepting those of the South Trap Range, were eroded in pre-Potsdam time together, possibly, with a part of the underlying Archean.

3. The porphyries found on Keweenaw Point at the contact between the Keweenaw series and the Potsdam sandstone may be in part either,

a. Marginal facies of the underlying Archean;

b. Intrusive in the early Keweenawan;

c. Early interbedded flows of the Keweenaw series; or,

d. Remnants of late Keweenawan intrusions by which the eastern margin of the series was broken up and its degradation hastened.

Seaman[1] gives a summary of the geological history of the Keweenawan copper range in Michigan, Wisconsin, and Minnesota. No new point on the geology of the region is added to those already recorded.

Hall[2] describes the pre-Cambrian crystalline rocks of the Minnesota river valley of southwestern Minnesota. These rocks appear in numerous exposures along the river, protruding from the drift, from southeast of New Ulm to Ortonville on the northwest. The great bulk of the crystalline rocks are granites and gneisses. These appear for the most part in the river bottoms, but stand also in a few isolated knobs on the higher ground south and west of the river. There are many varieties of granites and gneisses and all gradations between them. They are taken as a whole to represent the Archean or Basement complex.

Associated with the granites and gneisses are a much smaller number of exposures of gabbros and gabbro-schists. These present many varieties, all of which are believed to have resulted from the alteration of two original forms and their intergradations—a hypersthene-bearing gabbro and a hypersthene-free gabbro.

[1] Geology of the Mineral Range, by A. E. SEAMAN: First Ann. Rept. of the Copper Mining Industry of Lake Superior, 1899, pp. 49–60.

[2] The Gneisses, Gabbro-Schists and Associated Rocks of Southwestern Minnesota, by C. W. HALL: Bull. U. S. Geol. Surv., No. 157, 1899, pp. 131. With geological maps.

Peridotite is found in one exposure only in this valley, three miles southeast of Morton. The relations to the other rocks of the area could not be determined. Cutting the gneisses and gabbro-schists throughout the area are numerous dikes of diabase. They vary in width from a fraction of an inch to 175 feet. Their age is probably Keweenawan.

Southeast of Redstone and near New Ulm are exposures of quartzite associated with coarse quartzite conglomerate. Near Redstone the strike of the quartzites is N. 60–70° W., and their dip varies from 5–27° N. In New Ulm the strike is N. 15° E., and the dip varies from 10–15° S. E. The quartzite is believed to be the same as the quartzite found in a deep well at Minneopa Falls, near Mankato, Minn., which is covered by a quartzite conglomerate of Middle Cambrian age. The quartzite of Redstone and New Ulm is above the Archean granite and gneiss. It is believed to be of Huronian age, but whether Upper or Lower is unknown.

Overlying the crystalline rocks are Cretaceous shales and sandstones, which appear in rare exposures in the valley, and glacial drift.

Coleman[1] discusses areas mapped by Logan as Huronian north of Lake Huron and the east end of Lake Superior. The two contacts described by Irving and Van Hise as contacts of the Lower Huronian and Laurentian rocks were examined. At the first, on the islands four miles east of Thessalon, jasper and chert fragments were found in the conglomerate above the Laurentian, indicating that the conglomerate is probably a part of an upper series, younger than a series of rocks, not Laurentian, from which the jasper must have been derived. At the other contact, on the road between Sault Ste. Marie and Garden River, it is concluded that the conglomerate is possibly a crushed conglomerate formed by faulting instead of a water-formed rock.

Certain green and gray schists inclosed in the Laurentian gneisses are believed to represent the western Keewatin of Lawson.

The Laurentian and Huronian contact at Goulais and Batchawana bays was found to be in general of the nature of an eruptive contact, although a clear example of the inclusion of a typical Huronian rock in the Laurentian was not observed.

The slate-conglomerate of Doré River contains no bowlders that are distictly Laurentian. It contains only fragments of schists and

[1] Copper Regions of the Upper Lakes, by A. P. COLEMAN: Rept. of the Bureau of Mines, Ontario, Vol. VIII, Pt. 2, 1899, pp. 121–174.

eruptives from rocks which have been called Huronian. It probably has closer affinities to Lawson's Keewatin than to Logan's Original Huronian.

On the shores of Heron Bay the schist-conglomerate and slate were examined. The conglomerate contains fragments mainly of granite. These rocks are more closely allied to the Keewatin than to the Original Huronian type.

In general it is believed that Logan mapped as Huronian, rocks which are really Huronian and Keewatin.

The ascending succession for the region as indicated by the above facts is as follows: Keewatin, consisting mainly of basic green-schists; Laurentian, consisting mainly of moderately acid eruptives; and Huronian. The term Laurentian is confined to areas of granite and granitoid gneiss corresponding to the Ottawa Gneiss of eastern Canada, and having eruptive relations to the Keewatin.

The Keweenawan rocks of the various area on the north shore of Lake Superior were studied, but no important conclusions were reached differing from those of Irving. One variety of conglomerate, made up chiefly of underlying Laurentian rocks is common on the north shore, which apparently has not been found on the south shore.

Comments.—This discussion points toward the conclusion that the Original Huronian rocks of Logan are largely a series above and later than certain rocks to the west mapped by Logan as Huronian, and other rocks still farther to the west mapped by Lawson as Keewatin; further that the Laurentian rocks intrude the earlier series, and are unconformably overlain by the later Original Huronian series of Logan.

That the Original Huronian, in large part, is younger than some of the Keewatin rocks of Lawson is possible. The finding of chert and jasper fragments in the conglomerate cited by Irving and Van Hise as Lower Huronian would show that more of the series belongs to an upper division than was supposed.

However, as Dr. Coleman himself would fully agree, there still remains evidence to indicate that rocks of both Upper and Lower Huronian series are present in the Original Huronian area, and for the Keewatin of Lawson the evidence is conclusive that two or more series are represented. In view of this wide range of rocks in both areas, and the wide separation of the areas it is unsafe at present to make a definite statement concerning the relative ages of Lawson's Keewatin

and Logan's Original Huronian, based on lithological character and relations to the intrusives.

Dr. Coleman's conception of the Laurentian is the same as that attributed to the Canadian geologists in general in the comments on p. 440.

McInnes[1] describes the geology of the Seine River and Lake Shebandowan map-sheets, which cover an area extending west and northwest of Port Arthur, Ontario. Laurentian granites and gneisses with many variations occupy three fourths of the area. The relations to the overlying Keewatin and Coutchiching rocks, wherever they have been found in contact, have been those of intrusion.

The Huronian is represented by Coutchiching and Keewatin rocks. Coutchiching mica-schists and fine-grained gneisses, a continuation of Lawson's Coutchiching in the Rainy River district to the west, enter the area of the Seine River sheet on the west side. However, toward the east these rocks become associated with large quantities of gneisses, and for the eastern two thirds of the Seine River sheet and for the entire Lake Shebandowan sheet the gneisses are predominant and the belt is mapped as Laurentian. In other parts of the district the Keewatin schists, near their contact with the Laurentian gneisses, assume a character exactly similar to the Coutchiching schists and associated gneisses, and could not be lithologically distinguished. Indeed, the Coutchiching seems to be an extremely altered phase of the Keewatin.

In long bands infolded with the Laurentian and conforming in strike with the foliation of the gneiss are bands of Keewatin rocks varying greatly in width. They vary in composition from extremely basic igneous masses, and their derived products, to acid quartz-porphyries, and their derived products, and include also quartzites, conglomerates, and slates. The basic rocks form the largest volume of the rocks of the series. The series is separated lithologically in mapping into three divisions. There can be no doubt that the Keewatin here includes rocks which are of widely differing age.

Overlying unconformably the Keewatin rocks is the Steep Rock Lake series, so named from its occurrence in the neighborhood of this lake. The series is mapped as an upper division of the Keewatin series. As

[1] "The Geology of the Area Covered by the Seine River and Lake Shebandowan Map-Sheets, comprising Portions of Rainy River and Thunder Bay Districts, Ontario," by WM. MCINNES: Ann. Rept. Geol. Surv. of Canada, Vol. X, Pt. H, 1899, pp. 13-51. With geological map.

described by Smyth it comprises conglomerate, limestone, clay-slate, and various basic volcanic and intrusive rocks. Because of the folding of the series it is believed to be older than the Animikie strata of Thunder bay.

Animikie rocks occur in a small area in the southeast corner of the Shebandowan sheet. They overlie unconformably the Keewatin and Laurentian rocks, and from their stratigraphical relations to the overlying formation farther east on Lake Superior they are believed to be of Lower Cambridge age.

Comments.—The mapping of this area of these sheets has been largely lithological, the red granites and gneisses and their associated rocks of various ages being mapped as Laurentian, and the green rocks and the associated sedimentaries being mapped as Huronian. However, a distinct advance is made in seeing that some of the Coutchiching rocks are no more than metamorphosed Huronian or Keewatin rocks. This is a frank awowal that the Coutchiching series is a lithological, not a structural unit.

The Steep Rock Lake conglomerate was considered by Smyth and Pumpelly as the basal portion of the Lower Huronian, and the underlying rocks as Archean. McInnes has mapped the underlying rocks as Keewatin, and has included in them sedimentary and igneous rocks. He has not separated from them sedimentary rocks which may be the equivalent of the Steep Rock series.

C. K. LEITH.

Studies for Students

RESULTS OF TESTS OF WISCONSIN BUILDING STONE III[1]

In this the concluding paper on the testing of building stones I will summarize and discuss various tests which I made in the laboratory of the Wisconsin Geological Survey during the winter of 1897–8.

In examining the tests recorded in some of the reports on building stones I found them to be really of little value, either on account of the failure of the operator to describe carefully the methods employed in making the tests or owing to insufficient care in manipulation and computation. It has been noted that among sedimentary rocks the results of tests on samples from different parts of the same quarry may be very different. Such differences may be even more marked than those that occur between samples from different quarries within the same area. It is possible to select samples from a quarry which will give very high tests, while a greater part of the stone may be of the poorest kind. Valuable results can only be obtained when tests are made upon samples which are a fair average of the stone as it occurs in the quarry.

For making the tests herein discussed, the author endeavored to obtain samples which represented as nearly as possible average No. 1 stone. The tests were performed as nearly as possible in accordance with the instructions laid down in the previous paper. The utmost care was exercised in obtaining truthful results, and it is believed that the figures given are nearly accurate for the samples tested.

[1] The illustrations accompanying this paper are used by permission of the director of the Wisconsin Geological and Natural History Survey. A fuller discussion of these tests will be found in Bulletin No. IV of the Wisconsin Geological and Natural History Survey reports.

CRUSHING STRENGTH

The individual test which is employed perhaps more than any other to determine the strength and durability of a stone is the crushing strength test. For years certain architects and builders have relied upon this test almost exclusively for forming an estimate of the suitability of a stone for all kinds of public and private buildings. This general use of the crushing strength test is still prevalent in some sections of the country.

In order to be assured of the reliability of the machine in which the crushing strength tests were to be made, comparisons were made with tests made in two other machines on samples from the same quarries. One of the machines used was also calibrated to give positive assurance of its reliability. In making the tests, note was taken of the position of the sample in the machine with respect to bedding or schistosity.

Twenty-seven samples of granite from twelve different quarries were tested. The lowest crushing strength obtained was 12,704 pounds per square inch, while the highest was 47,674 pounds per square inch. The average crushing strength of all the samples tested was 27,023.7 pounds per square inch. The minimum crushing strength was above the maximum crushing strength obtained for sandstone, and was obtained on a sample of granite gneiss in which the lamination was diagonal to the direction of the pressure. As far as my knowledge extends the maximum crushing strength is the highest yet recorded for any rock tested in the United States. It was obtained from a sample of rhyolite on which the pressure was applied normal to the head or in the direction of the rift.

It has been generally supposed that the crushing strength of a stone is least in the direction of the rift or lamination, but apparently this is not true in the case of the rhyolite in question. This rhyolite consists of elongated crystals of feldspar and other minerals in a very dense groundmass, forming what one might consider a very compact bundle of fibers. A rock with such a structure can apparently sustain a greater pressure when applied in the direction of these fibers than when applied across them.

Further, a careful examination of the polished faces of this rock shows that the feldspar crystals are broken by numerous cross fractures. These small, scarcely perceptible fractures may account in part for the less load which the rock is capable of sustaining normal to the rift. The cone which remained after crushing this sample of rhyolite is shown in Plate I.

The highest crushing strength obtained for true granite was 43,973 pounds per square inch, which was obtained on a sample of the Montello stone. This, so far as my knowledge goes, is the highest crushing strength that has been recorded for any United States granite. It exceeds the highest test on the Fourche Mountain granite[1] of Arkansas by nearly 15,000 pounds per square inch, while the highest test on the granite from St. Cloud,[2] Minn., is 16,000 pounds less than this. The granite from Redgranite, Waushara county, also gave a crushing strength of over 36,000 pounds per square inch, which exceeds the highest test made on the Fourche Mountain granite by 7000 pounds per square inch. These illustrations give evidence that in at least three different areas in Wisconsin granite and rhyolite occur, which, as far as known, surpass in strength granite or rhyolite from any other quarry in the United States.

Most of the granite samples broke with an explosion. Ordinarily an upper pyramid or cone, such as shown in the accompanying illustration, Plate I, was all that remained after the test. In a few cases a lower or opposite pyramid remained, but as a rule this part of the sample was reduced to powder. In many of the cones that remained a concentric structure had been developed through the pressure, which had much the appearance of cleavage. This is nicely shown in the accompanying illustration, Plate II.

[illegible] tests were made on limestone from eleven different quarries. The strongest sample tested gave a crushing strength of [illegible] pounds per square inch, which is about [illegible] pounds higher than any known test recorded for limestone.

[1] Annual Rep. Arkansas Geol. Survey, [illegible], Vol. II, p. [illegible].

[2] Geological and Natural History Survey of Minnesota, [illegible], Vol. I, p. [illegible].

dolomite, or marble in the United States. The stone which gave this test was a thoroughly crystalline, well compacted, and homogenous dolomite. The weakest sample tested gave a crushing strength of a little over 6600 pounds per square inch. The strength of the weakest limestone is very little less than that of the ordinary sandstones tested. The sample which gave the highest test was from the Marblehead Lime and Stone Company's quarry in the Niagara formation. Other samples from the Niagara formation gave tests of 39,983 pounds, 36,731 pounds, 33,485 pounds, 32,171 pounds, and 31,800 pounds per square inch.

The crushing of the samples of limestone was ordinarily accompanied with less noise than the granite. Occasionally the samples scaled off along the edges and corners before the maximum load was applied. In some cases two pyramids were developed, but as a rule, only one remained after crushing the more perfectly prepared cubes. The pyramids resulting from the crushing of limestone are ordinarily much steeper and more slender than those of the granite. Occasionally wedge-like forms were developed which resembled the wedge-shaped pyramids of the granite, as shown in Plate II, Fig. 2 and Plate IV, Fig. 3. Occasionally the samples are reduced to splinters, even the pyramids falling in pieces when raised from the steel plate. The cone which remained after the "record sample" of limestone was crushed is shown in Plate III, Fig. 6. Other typical pyramids resulting from crushing limestone samples are shown in Plate III, Figs. 1–5.

The crushing strength was determined for forty-five samples of sandstone from eleven different quarries. The samples from several of the quarries were thoroughly indurated while others were very soft and incoherent. In most cases the cementing material was silica but in some of the weaker samples iron oxide was the principal bonding constituent. Compared with the strength of the granite and limestone, the sandstone may be considered relatively weak. The sample which gave the highest strength test was from the quarry of the Chicago and

Northwestern Railway Company at Ablemans. This sample gave a test of 13,431 pounds per square inch. The lowest test was 1658 pounds per square inch, made on a sample of Lake Superior brown sandstone tested on edge. The lowest test across the bed was 2502 pounds made on a sample of Dunnville sandstone. The average strength of all the sandstone samples tested, one half of which were on edge and the other half on the bed, was 6361 pounds per square inch. The average crushing strength of twenty tests of the Lake Superior brown sandstone, one half of which were on edge and the other half on the bed, was 4618 pounds per square inch. This is a somewhat higher average crushing strength than that recorded for the Bedford öolitic limestone of Indiana.[1]

The weaker the sandstone and the more uniform the grains, the more perfect are the pyramids which develop. In the stronger samples the pyramidal form is replaced by the conical. In the samples of moderate strength almost perfect pyramids form on both the upper and lower sides, as shown in the accompanying illustration, Plate IV, Figs. 1 and 4.

In performing these tests my attention was called to the fact that the crushing strength on edge of the weakest samples was considerably less than that on the bed, while in the stronger rocks the difference was much less. The compressive strength of several different limestones was higher when the pressure was applied along the bed than when applied across it. The Berlin rhyolite, which is the strongest stone tested, gave the highest strength test when the pressure was applied in the direction of easiest parting. These results indicate that there are exceptions to the general rule that a stone will withstand the greatest pressure when applied normal to the bed. Apparently the rule applies only to stone which has a low compressive strength. When the compressive strength is very high the opposite result is fully as likely to occur and may even prove the rule.

The manner in which the cubes of stone break indicates to a greater or less extent the strength of the stone. Crushing a

[1] Twenty-first Annual Report of the Indiana Department of Geology and Natural Resources, p. 317.

stone which has a compressive strength of less than 10,000 pounds per square inch usually results in the formation of two quite well defined pyramids. The pyramids resulting from crushing a stone with a compressive strength of between 10,000 and 20,000 pounds per square inch are ordinarily less perfect. The pyramids resulting from testing stone of this class are frequently wedge-shaped but more often they are intermediate between a pyramid and a cone. The crushing of cubes having a compressive strength of over 30,000 pounds per square inch usually results in the formation of only one pyramid which has more of a conical than pyramidal outline.

In crushing the granite and also some of the limestone and sandstone cubes a concentric structure was developed similar to that illustrated in Plate II, Figs. 4, 5, and 6.

TABLE I.

CRUSHING STRENGTH[1]

Ultimate Strength in Pounds per Square Inch.

	Highest test	Lowest test	Average
Granite and rhyolite: twenty-seven samples from twelve different quarries..............	47,674	12,704	27,023.7
Limestone: thirty-one samples from eleven different quarries..........................	42,787	6,675	25,312.8
Sandstone: forty-five samples from eleven different quarries......	13,699	1,658	6,125.0

TRANSVERSE STRENGTH

The determination of the modulus of rupture is of as great if not greater importance than the crushing strength. As previously indicated, it is especially valuable in determining the required thickness of a stone which is intended to be supported at the ends, and which carries a heavy weight of superstructure in the middle.

The modulus of rupture was determined for only two Wisconsin granites. The results in each case were over 2300 pounds

[1] For detailed results of individual tests see Bulletin No. IV, Wisconsin Geological and Natural History Survey, "Building and Ornamental Stones," 1898.

per square inch. The average transverse strength of the Montello granite was over 3780 pounds per square inch. The samples broke suddenly, and the fracture extended diagonally across the center of the pieces.

The modulus of rupture was determined for samples of limestone from eight different quarries. The results ranged from 1164.3 pounds to 4659.2 pounds per square inch. The highest result obtained was on a sample of stone from the Laurea Stone Company's quarry at Sturgeon Bay. The stone from the Marblehead Lime and Stone Company's quarry at Eden gave a modulus of rupture of 3632 pounds per square inch. All of the transverse strength tests were high. The samples broke very close to the center and much quieter than the granite.

The modulus of rupture was determined for sandstone from six different quarries. The results ranged from 362.9 pounds to 1324 pounds per square inch. The highest test obtained was on samples from the Chicago & Northwestern Railway Company's quarry at Ablemans. Eight tests of the brown sandstone from the Lake Superior region gave an average modulus of rupture of about 500 pounds per square inch.

A comparative examination of the results shows that the finely crystalline limestone possesses a higher modulus of rupture than either the sandstone or granite. However, it is ordinarily less rigid than either of these stones, and is more liable to sag when suspended at the ends.

TABLE II

TRANSVERSE STRENGTH

Modulus of Rupture in Pounds per Square Inch

	Highest test	Lowest test	Average
Granite and rhyolite: four samples from two different quarries	3,909.7	2,324.3	3,156.2
Limestone: ten samples from eight different quarries	4,659.2	1,164.3	2,761.15
Sandstone: sixteen samples from six different quarries	1,324	150.2	558.8

MODULUS OF ELASTICITY

Up to the present time very few determinations of the modulus of elasticity have been made, especially in the United States. However, a knowledge of the modulus of elasticity is of value to architects and builders in many of their calculations.

The modulus of elasticity was determined for granite from eleven different quarries. The results varied between wide limits, ranging all the way from 156,000 pounds to 2,070,000 pounds per square inch. The first result is comparatively low, while the latter is very high. Four samples of granite from Wausau gave tests of from 1,040,000 to 1,815,000 pounds per square inch. The Athelstane granite from Amberg tested very close to 1,000,000 pounds per square inch. The Pike River gray granite from the same place tested nearly 1,500,000 pounds per square inch.

The modulus of elasticity was determined for limestone from four different quarries. The results obtained varied from 31,500 pounds per square inch to 869,400 pounds per square inch. The highest result was obtained for limestone from the Washington Stone Company's quarry which is located at Sturgeon Bay.

The modulus of elasticity was determined for samples of sandstone from ten different quarries. The results of these tests varied from 32,000 pounds to 400,800 pounds per square inch. The highest result was obtained for samples of white sandstone from the Chicago & Northwestern Railway Company's quarry at Ablemans. The modulus of elasticity of the Lake Superior brown sandstone ranged from 56,000 to 387,900 pounds per square inch.

In general it will be noted that the modulus of elasticity corresponds approximately with the crushing and transverse strength of the different rocks tested. The crushing strength, transverse strength, and modulus of elasticity were all lower for the sandstone samples tested than for either the limestone or granite.

TABLE III

MODULUS OF ELASTICITY

In Pounds per Square Inch

	Highest test	Lowest test	Average
Granite and rhyolite: twenty-one samples from eleven different quarries	2,070,000	156,000	1,068,634
Limestone: eleven samples from five different quarries	1,835,700	31,500	786,145
Sandstone: twenty-eight samples from ten different quarries	400,800	32,000	163,861

HARDNESS

The hardness of a stone can be easily determined with the abrading machine known as the Deval.[1] For making this test a definite quantity (5 kg) of cubical pieces of stone from two to two and one half inches in diameter are placed in one of the cylinders of this machine, which is then rotated for five hours at a rate of about thirty-three revolutions per minute. The percentage of dust which is worn off by this treatment is the measure of the hardness of the stone. The coefficient of wear, which is another and the usual method of expressing the hardness, is computed from the following formula:

$$Q = \frac{20 \times 20}{W},$$

in which

Q = the coefficient of wear

W = the quantity of dust formed.

Two samples of granite from each of two quarries were tested in the abrading machine, with the results given in Table IV. Quartzite from one quarry, trap rock from one quarry, and limestone from seven quarries were also tested, with the results given in Table IV.

TABLE IV

HARDNESS OR COEFFICIENT OF WEAR

	Highest	Lowest	Average
Granite: four samples from two quarries	4.88	3.54	4.14
Trap: two samples from one quarry	3.03	2.07	2.55
Quartzite: two samples from one quarry	2.70	2.28	2.49
Limestone: fourteen samples from seven quarries	2.22	0.79	1.51

[1] For description of this machine see the Report of the Massachusetts Highway Commission for 1899, pp. 59, 60.

SPECIFIC GRAVITY

The weight of a rock per cubic foot will increase with the specific gravity proper and decrease with the percentage of pore space. As indicated in a previous paper, the average specific gravity of the mineral constituents is taken as the specific gravity proper of the rock. Following this conception the pore spaces are not considered a part of the rock mass.

Twenty-five determinations of specific gravity were made on samples of granite from fourteen different quarries. The maximum specific gravity obtained was 2.713 and the minimum 2.629, while the average of all determinations was 2.655. Tests on twenty-two samples of limestone from eleven different quarries gave an average specific gravity of 2.806. The maximum specific gravity was 2.856 and the minimum 2.700. Tests on thirty-two samples of sandstone from sixteen different quarries gave an average specific gravity of 2.618. The maximum specific gravity was 2.660 and the minimum 2.524.[1]

In the case of the sandstone it is to be observed that the iron oxide which constitutes a part of the cement of the brown sandstone is not present in sufficient quantity to appreciably affect the specific gravity. The specific gravity of the granite, however, is influenced appreciably by the abundance of the ferro-magnesium minerals, as exemplified in the case of the Athelstane granite from Amberg, which gave the highest specific gravity test. An admixture of quartzose material naturally lowers the specific gravity of limestone.

The stone which gave the highest specific gravity was a very compact and finely crystalline dolomite, and it is interesting to note that samples from this same quarry gave the highest crushing and transverse strength of any of the limestone or dolomite tested.

WEIGHT PER CUBIC FOOT

Determinations of the weight per cubic foot were made for twenty-five samples of granite from fourteen different quarries.

[1] It is thought that this low specific gravity is due to an unknown error in manipulation.

The average weight per cubic foot according to these determinations was 163.29 pounds. All of the granites tested weighed within five pounds per cubic foot of one another.

The average weight of twenty-two limestone samples from eleven different quarries was 166.70 pounds per cubic foot. The maximum weight was 176.69 pounds per cubic foot and the minimum 148.50 pounds per cubic foot. The average weight of thirty-two samples of sandstone from sixteen different quarries was 136.36 pounds per cubic foot. The maximum weight was 153.63 pounds per cubic foot and the minimum 115.55 pounds per cubic foot.

POROSITY AND RATIO OF ABSORPTION

As has been previously pointed out, the porosity gives the volume relation between the pores and the mass of the stone, while the ratio of absorption gives the weight relation. None of the granites tested had a porosity of more than 1 per cent., while the porosity of most of the samples was about .45 of 1 per cent. Owing to the interlocking character of the grains, the pores of a granite are much smaller than those of arenaceous limestone or sandstone. The water is therefore taken up and given off very slowly. The ratio of absorption of the granite samples tested was nearly the same as the porosity.

The limestone samples gave porosities ranging from 13.36 per cent. to .14 of 1 per cent. The sample having a porosity of 13.36 per cent. had a ratio of absorption of about 5.6 per cent. The samples from the Marblehead Lime and Stone Company's quarry, which gave the high crushing and transverse strength tests, had a porosity of about .70 of 1 per cent.

The porosity of the sandstone samples ranged from 4.81 per cent. to 28.28 per cent. The average porosity of the brown sandstone samples was between 19 and 20 per cent. In the case of the samples of sandstone having a porosity of 28.28 per cent. the ratio of absorption was 15.22 per cent. The Lake Superior brown sandstones gave an average ratio of absorption of less than 10 per cent.

The walls of a building constructed out of a porous stone are seldom completely saturated with water, although they may be wetted by the water of imbibition which adheres as a film to the individual grains and is thus conducted through the body of the wall. If a stone with pores of capillary size should be saturated in any part with water and the supply be discontinued the interstatial water would be very quickly drawn off at the surface or at the base of the wall through capillarity. It rarely happens that atmospheric conditions are such that a stone with capillary pores can become saturated with water and freeze before the water is sufficiently dissipated to prevent injury.

Rocks in which the grains are closely compacted, without respect to size, will have a small percentage of pore space and also pores of very small size. Many of the pore spaces of the granite and limestone are certainly of not greater than sub-capillary size. Water is taken up and given off by a rock having pores of this size much more slowly than by one in which the pores are of capillary dimensions. When the sub-capillary pores of a rock contain water in any quantity they should be theoretically filled. The sub-capillary pores near the exposed surface of a stone wall may be filled by long-continued rains, although the water may never penetrate to any considerable depth. If such a period of weather is followed by freezing conditions a stone in which the pores are of sub-capillary size will be in greater danger than one having pores of capillary size. It should be remembered that stone is damaged by freezing only when the pores are over nine tenths filled with water.

A wall built out of granite or other stone in which the porosity may be very low, but the pores of sub-capillary size, is in as great danger from alternate freezing and thawing as a wall built out of sandstone or other rock in which the porosity is 15 or 18 per cent., but in which the pores are of capillary size. It must be understood that this does not apply to laminated, bedded, or shaly stone, between the layers of which the water may collect more rapidly than it can be carried off through the pores. Water which is thus collected along bedding or other parting

planes cannot be considered under the head of interstatial water, although it is a very prominent cause for the disintegration of building stone.

TABLE V

	Specific gravity	Porosity	Ratio of absorption	Weight per cubic foot
Granite:				
Maximum	2.713	.55	.500	169.05
Minimum	2.629	.019	.04	163.29
Average	2.655	.329	.158	164.98
Limestone:				
Maximum	2.856	13.36	5.60	176.69
Minimum	2.700	.53	.19	148.50
Average	2.806	4.89	1.946	166.70
Sandstone:				
Maximum	2.660	28.28	15.22	153.63
Minimum	2.524	4.81	2.00	115.55
Average	2.622	15.89	7.486	136.36

FREEZING AND THAWING TESTS

As said in a previous paper, the difficulties involved in manipulation and the many conditions which must be considered before conclusions can be drawn from quantitative results of freezing and thawing tests, have apparently had the effect of almost excluding these determinations from reports on building stones. The effect of alternate freezing and thawing may be manifested in three ways: (1) cracks may form; (2) small particles or grains may be thrown off from the surface, occasioning a loss in weight; (3) the cement may be weakened or the grains broken, causing the strength to be materially lessened.

Cracks.— Cracking, as a result of freezing, is seldom observed in the laboratory tests, owing to the careful manner in which the samples are usually prepared.

Loss in weight.— Small particles are frequently shoved off from the surface of a sample which is subjected to alternate freezing and thawing. Where incipient joints occur small flakes are also sometimes loosened by pressure of the freezing water. Many of the grains at or near the surface of sandstone samples become loosened in the process of sawing or hammer dressing. These grains usually adhere to the sample so loosely that they

fall away from the parent mass under very moderate pressure. Loose particles at the surface are naturally more plentiful in the case of sedimentary rocks such as sandstone than they are in the case of igneous rocks or finely crystalline limestone. The loss in weight due to alternate freezing and thawing *will depend mainly* upon the manner in which the samples have been dressed and the kind of stone tested. The experiments which I have performed have demonstrated to my satisfaction that alternate freezing and thawing for a period of thirty-five days results in scarcely more than the removal of the loosened grains or fragments from the surface. Any loss in weight which may be partly accounted for by the manner of preparing the samples does not indicate the extent to which the stone has been injured.

Loss in weight due to freezing and thawing was determined for eighteen samples of granite from eleven different quarries. The loss in weight in these cases did not exceed .05 of 1 per cent. on a mass of about 350 to 360 grams. In the case of limestone, in which twenty-one samples from eleven different quarries were tested, the loss did not exceed .3 of 1 per cent., being, as a rule, less than .1 of 1 per cent. The loss in weight of the sandstone samples, of which twenty-four from twelve different quarries were tested, did not exceed .62 of 1 per cent. and averaged about .28 of 1 per cent.

TABLE VI

FREEZING AND THAWING TESTS

Loss per cent. of weight

	Highest test	Lowest test	Average
Granite and rhyolite: sixteen samples from eleven different quarries....................	.05	.006	.035
Limestone: twenty-one samples from eleven different quarries..........................	.30	.005	.0753
Sandstone: twenty-four samples from twelve different quarries..........................	.62	.015	.276

Such losses in weight are almost insignificant, and are valuable mainly in showing that the more loosely compacted

sandstone samples have more of the exterior grains loosened in preparation than do the granite, rhyolite, and limestone. It is very probable that had these same samples been subjected to a second period of alternate freezing and thawing, the granite, limestone, and sandstone would have agreed more nearly in the loss by weight.

Loss in crushing strength.—The result of alternate freezing and thawing is more clearly manifested by a decrease in the crushing strength of the rock than by the loss in weight. It is very evident that if a stone having sub-capillary pores is subjected to alternate freezing and thawing for a considerable period, the adhesion of the particles will be weakened and the cement perhaps shattered or broken. This will not necessarily occasion an immediate loss in weight, but must necessarily decrease the strength of the stone. The samples which were subjected to alternate freezing and thawing for thirty-five days were broken in a testing machine to determine their crushing strength. The crushing strength thus obtained was compared with the crushing strength obtained from the samples of fresh stone. With a few explainable exceptions, the crushing strength of the frozen samples of granite was much less than that of the fresh. The crushing strength of the frozen samples from ten different granite quarries was less than the crushing strength of the fresh samples by from 2201 pounds to 13,075 pounds per square inch. In the case of limestone samples from eleven different quarries the frozen samples from eight showed a loss in crushing strength of from 571 pounds to 18,714 pounds per square inch. Among the frozen samples of sandstone from ten different quarries, six gave crushing strength tests which ranged from 326 to 6264 pounds per square inch lower than the crushing strength of the fresh samples. The average loss for all the frozen samples of each kind of rock is given in Table VII. Table VIII gives a comparison between the average crushing strength of fresh and frozen samples, and also the average loss through freezing.

TABLE VII

ULTIMATE STRENGTH IN POUNDS PER SQUARE INCH OF FROZEN SAMPLES

	Highest test	Lowest test	Average
Granite and rhyolite: sixteen samples from twelve different quarries	37,027	9,765	22,875
Limestone: twenty-one samples from eleven different quarries	34,784	5,584	18,267
Sandstone: twenty-four samples from twelve different quarries	9,245	2,116	4,724

TABLE VIII

COMPARATIVE CRUSHING STRENGTH OF FRESH AND FROZEN SAMPLES

	Crushing strength of fresh samples	Crushing strength of frozen samples	Difference, or loss in strength through freezing
Granite and rhyolite: average difference in strength of twenty-three fresh and eighteen frozen samples from eleven different quarries	29,696	22,793	6,903
Limestone: average difference in strength of twenty-one fresh and twenty-one frozen samples from eleven different quarries	25,222	18,267	6,955
Sandstone: average difference in strength of eighteen fresh and twenty-four frozen samples from ten different quarries	5,461	4,453	1,008

These experiments illustrate two points which I have made in the previous discussion: (1) that the results of freezing and thawing can be best estimated from the loss in crushing strength; (2) that the larger the pores, without respect to the percentage of pore space, the less will be the injury from freezing and thawing. There is little doubt but that a stone having a high percentage of pore space, *if completely saturated* with water and frozen, will suffer greater injury than one with a lower percentage. But the conditions under which freezing takes place must be considered before conclusions reached are of any practical value. These conditions include a time element which enters to modify very materially the results. After making this time element as short as the conditions under which the experiments

were performed would permit, it was demonstrated that the strength of the sandstone, which had a high percentage of pore space, was less affected by freezing and thawing than the strong granites and limestones having a low percentage of pore space. It was naturally thought that the Dunnville sandstone, which has 28.28 per cent. of pore space, and consists of relatively fine particles, would experience a greater loss in strength than any of the other rocks tested. The results, however, give evidence that a rock as fine-grained and poorly-cemented as this, with pore spaces which are little greater than sub-capillary size, is but slightly injured by alternate freezing and thawing.

It has been a matter of frequent observation that limestone and marble suffer more by hard freezing immediately after being taken from the quarry than other stones which have a higher porosity. This has usually been spoken of as exceptional, but I venture to say that between limestone, marble, and sandstone, the two former can furnish more examples of injury by freezing of interstatial water than the latter. A reasonable explanation for this result would be that the pore spaces in the limestone are usually of sub-capillary size, while those in the sandstone are mainly of capillary size.

EFFECTS OF SULPHUROUS ACID GAS

Limestone, dolomite, and marble are the only stones which are to any extent injured by sulphurous acid gas. Eleven samples of limestone and dolomite from as many different quarries were exposed for forty-four days to sulphurous acid gas in a moist atmosphere. Some of the pieces of limestone were colored yellow, others were slightly etched on the surface, while many of the samples showed a glistening precipitate of magnesium salts. By washing the samples the magnesium salt was taken into solution and through this the weight of the sample was slightly decreased.

The deterioration of limestone or dolomite in a moist atmosphere laden with sulphurous acid gas is apparently not very rapid. Where deterioration does not proceed very rapidly under

such extreme conditions, in an ordinary atmosphere it would be many years before the gas would have any appreciable effect upon the limestone in the walls of a building.

EFFECT OF CARBONIC ACID GAS

Eleven samples of limestone and dolomite were tested to determine the effects of carbonic acid gas in a moist atmosphere. After treatment for forty-four days there was apparently no deterioration either in weight or color.

EFFECT OF HIGH TEMPERATURE

Few experiments have thus far been performed to determine the limit of temperature which different kinds of stone will stand without injury.[1] It is known, however, that a stone will stand a much higher temperature when heated and cooled slowly than when heated and cooled rapidly.

Samples of granite from six different quarries were tested in a muffle furnace to determine the temperature which they would stand without being destroyed. The samples were all practically uninjured up to a temperature of 1200° F. but most of them were destroyed before a temperature of 1500° F. was reached. Eleven different samples of limestone from as many different quarries were tested and each of them was partially calcined before a temperature of 1400° F. was reached. The eleven samples of sandstone which were tested were mostly destroyed at a temperature of less than 1200° F. although in one instance a temperature of 1500° F. apparently left the sample uninjured.

All the heated samples when struck with a hammer or scratched with a nail emitted a sound very similar to that given off by brick. Planes of lamination were brought out more distinctly as the temperature increased.

The samples of granite cracked differently depending upon whether they were coarse or fine grained. The very coarse grained granite samples broke in a great many places and may be said to have exploded. The cracks were so numerous in one

[1] See "Notes on Building Stones" by HIRAM CUTTING, Montpelier, Vt., 1880.

EXPLANATION OF PLATE I

RESULTS OF CRUSHING GRANITE AND RHYOLITE

The figures in this plate illustrate some of the more perfect cones resulting from crushing the stronger samples of granite and rhyolite. Fig. 1 is a typical result for granite of this class, while Fig. 3 is a typical rhyolite cone. This latter cone resulted from crushing a two-inch cube of granite, which gave a test of nearly 48,000 pounds per square inch. It will be further observed that Figs. 4 and 5 have wedge-shaped apices similar to those illustrated in Pl. IV, Fig. 3.

JOUR. GEOL., VOL. VIII, NO. 6 Plate I

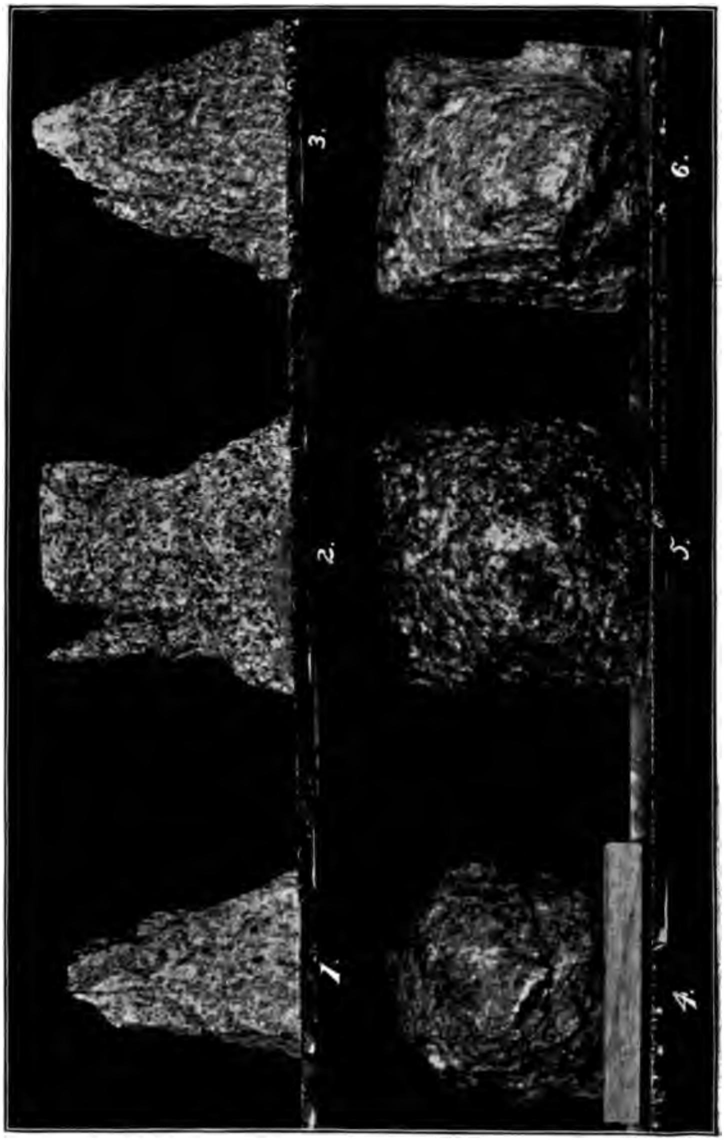
Results of crushing granite and rhyolite cubes.

EXPLANATION OF PLATE II

FIGS. 1, 2, and 3.—These samples illustrate the different forms developed in crushing granite cubes. The one on the left is a typical cone. The one on the right has a tendency toward the wedge-shaped form, while the one in the middle is a typical wedge form. The upper part of this wedge is a sharp ridge from one end to the other.

FIGS. 4, 5, and 6.—These three figures have their apices pointing toward the observer. They are all well shaped cones, in which there has been especially well developed the concentric structure referred to in the text.

Jour. Geol., Vol. VIII, No. 6 Plate II



Results of crushing granite cubes.

EXPLANATION OF PLATE III

The figures in this plate illustrate the results of crushing samples of the strongest limestone of Wisconsin. The sample in the lower right hand corner, Fig. 6, gave a crushing strength test of 42,787 pounds per square inch, which is thought to be the highest record obtained for any limestone, dolomite, or marble quarried in the United States. This sample shows, near the apex of the somewhat irregular cone, the concentric cleavage structure, which is typically developed in the granite.

JOUR. GEOL., VOL. VIII, No. 6

Plate III

Results of crushing limestone cubes.

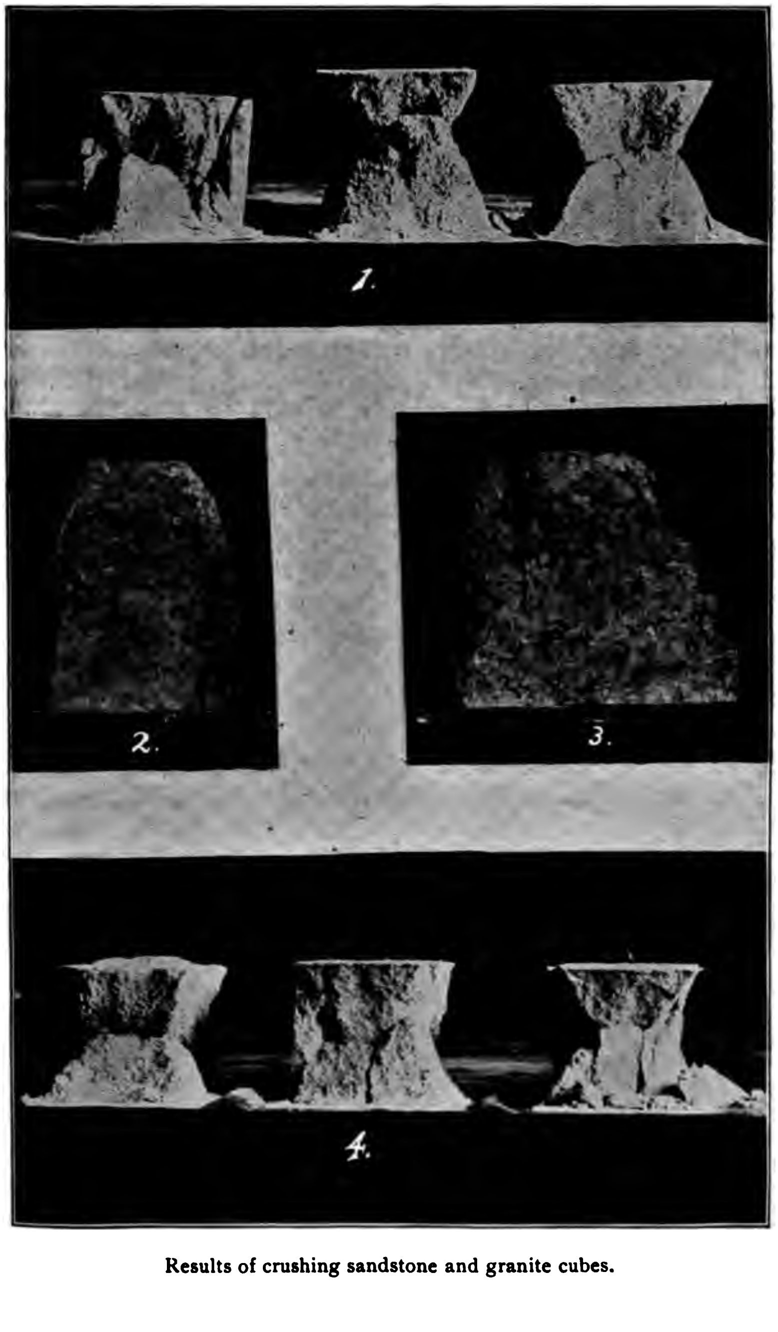
EXPLANATION OF PLATE IV

FIG. 1.—Samples of brown sandstone in which the pyramidal forms are well developed.

FIGS. 2 and 3.—Samples of granite. Only the upper wedge or pyramid was developed in each cube. Fig. 2 approaches the conical form, which ordinarily results from crushing granite. (See Pl. II.) Fig. 3 is the typical wedge-shaped form, which often results from crushing granite of medium strength.

FIG. 4.—Samples of brown sandstone in which the pyramidal structure is well developed. These are typical results obtained from crushing sandstone of ordinary strength. It should be observed that the samples which have a low or medium crushing strength are the only ones in which two equally well developed pyramids occur.

JOUR. GEOL., VOL. VIII, No. 6 Plate IV



Results of crushing sandstone and granite cubes.

EXPLANATION OF PLATE V

The samples numbered 1, 3, 6, 7, 13, and 16 are granite; those numbered 8, 9, 10, and 11 are limestone; and numbers 2, 3, 4, 12, 14, and 15 are sandstone. Samples numbered 5, 6, and 13 were cooled suddenly by immersing them in cold water, while the remaining were cooled gradually. Number 6 is fine grained, number 5 medium grained, and number 13 coarse grained granite. It is simply necessary to direct attention to these samples, for one to see how the difference in grain influenced the manner of cracking.

The limestone samples were partly calcinated. Where the quicklime has been removed the samples have the rounded edges noticed in numbers 9 and 10.

The sandstone samples are, to all outward appearances, uninjured, as shown in samples numbered 2 and 15. The chipping of the corners and edges in numbers 4, 12, and 14 was occasioned by pressing the thumb against the parts broken off, which in spite of the uninjured appearance of the samples, indicates the friable character of the stone after heating to the extreme temperature of 1300°–1500° F.

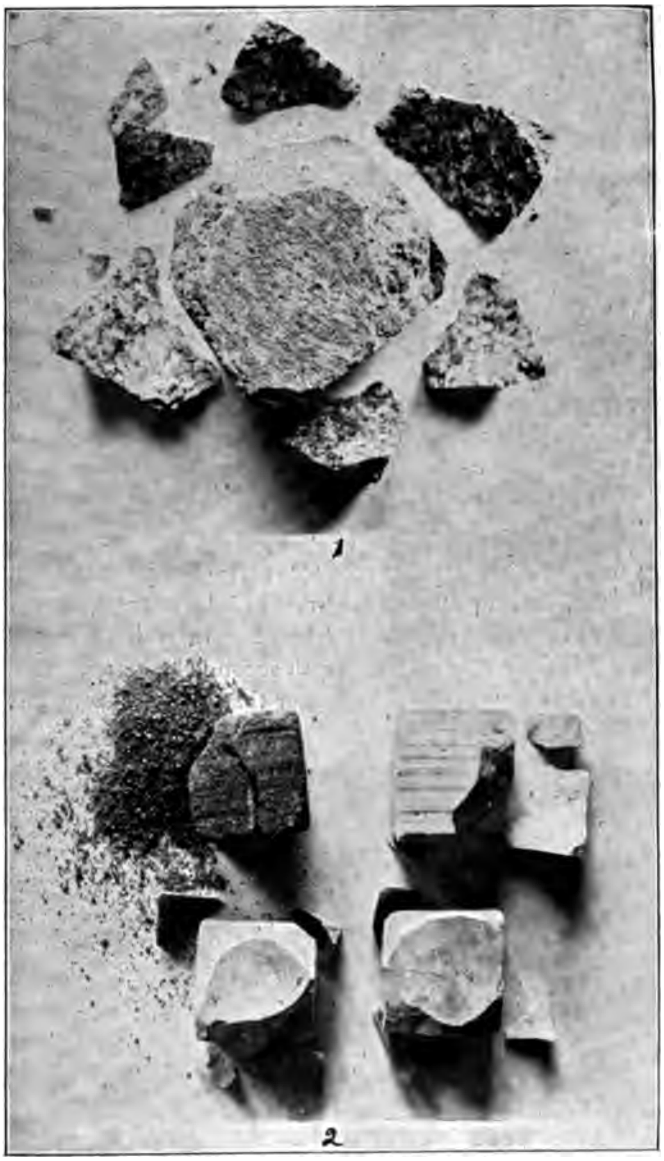
JOUR. GEOL., VOL. VIII, NO. 6 Plate V

Results of subjecting different kinds of stone to high temperatures.

EXPLANATION OF PLATE VI

FIG. 1.—A sample of medium-grained granite heated to a temperature of from 1300°–1500° F., and suddenly cooled by immersing in cold water. This figure is a good illustration of the result of throwing a stream of water on the walls of a burning building, which is con structed out of granite of this texture.

FIG. 2—The sample in the upper left hand corner is sandstone which has become so friable by being heated to a temperature of 1300°–1500° F., that it crumbles when pressed between the fingers. The remaining samples are limestone. They have flaked off at the corners, due to having been quickly cooled from a very high temperature. Such results may frequently be noticed in the limestone walls of buildings which have been destroyed by fire.



Results of rapidly cooling samples of granite, limestone, and sandstone that have been heated to a high temperature.

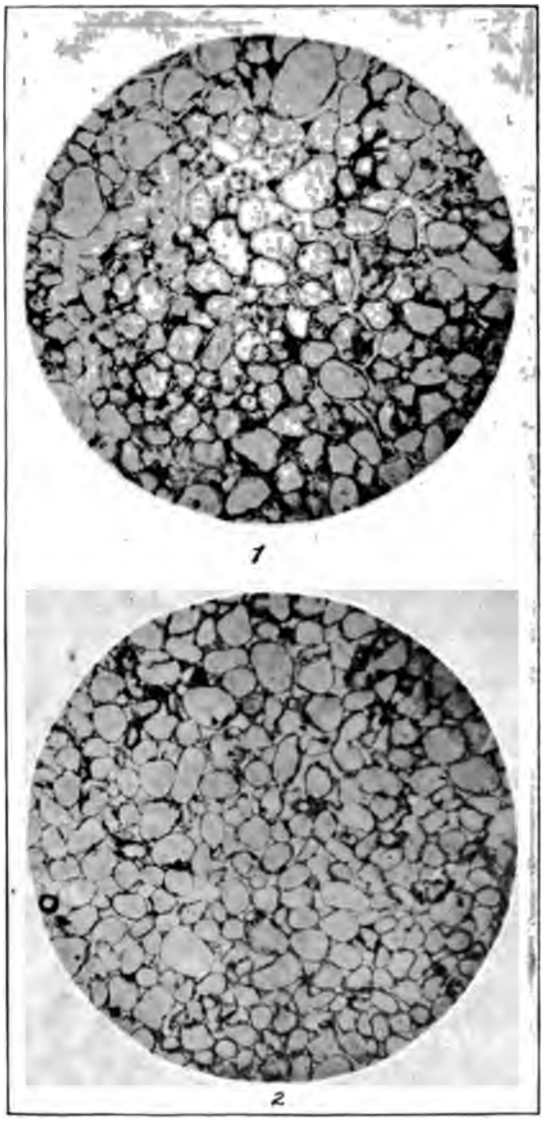
EXPLANATION OF PLATE VII

FIG. 1.—Section No. 4721. (× 12.)[1] Red sandstone from LaValle. This is an excellent illustration of a sandstone in which the grains were originally uniformly well rounded, and later enlarged and cemented with silica. The enlargements are nicely shown in many places in the section. The brown rims of iron oxide which separate the original grains from the secondary quartz are very distinct in the figure.

FIG. 2.—Section No. 4720. (× 12.) Brown sandstone from Argyle. This section illustrates a rock in which the grains are well-rounded and cemented with iron oxide, but in which the individuals have not been generally enlarged with secondary quartz. On account of this the stone is considerably weaker than the one from LaValle.

[1] Magnified twelve diameters.

Jour. Geol., Vol. VIII, No. 6 Plate VII



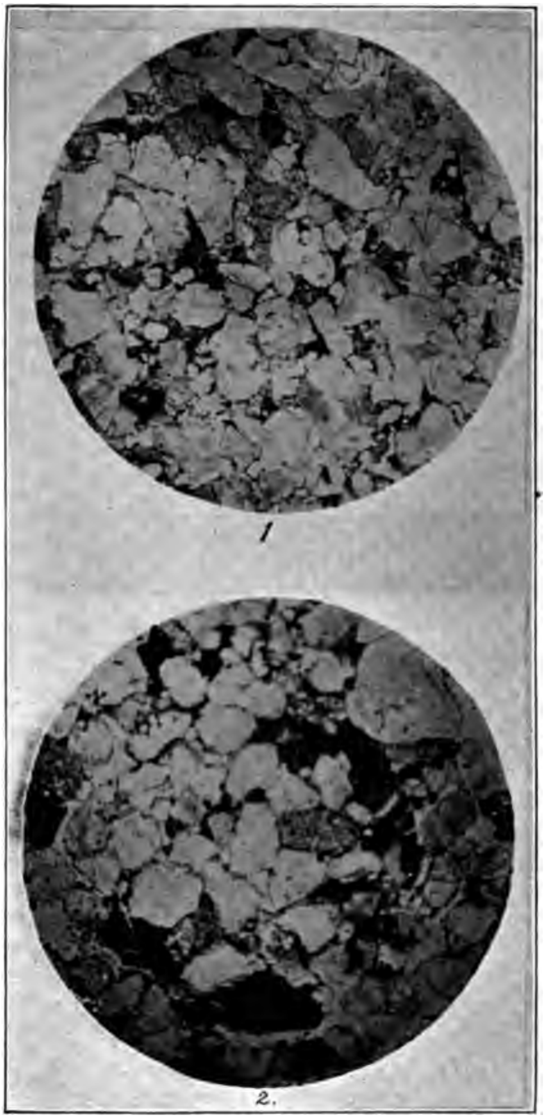
Thin sections of sandstone.

EXPLANATION OF PLATE VIII

FIG. 1.—Section 4719 (× 12). Lake Superior brown sandstone from the Chequamegon Area. This section is composed mainly of quartz and the accompanying figure shows the size, shape and arrangement of the grains. It will be observed that they do not interlock.

FIG. 2.—Section 4714 (× 12). Lake Superior brown sandstone from the Chequamegon Area. The grains are somewhat better rounded in this, than in the preceding section. One will quickly notice the secondary quartz which in many places cements the individual grains together. Occasional grains of feldspar occur among those of quartz.

Jour. Geol., Vol. VIII, No. 6 Plate VIII



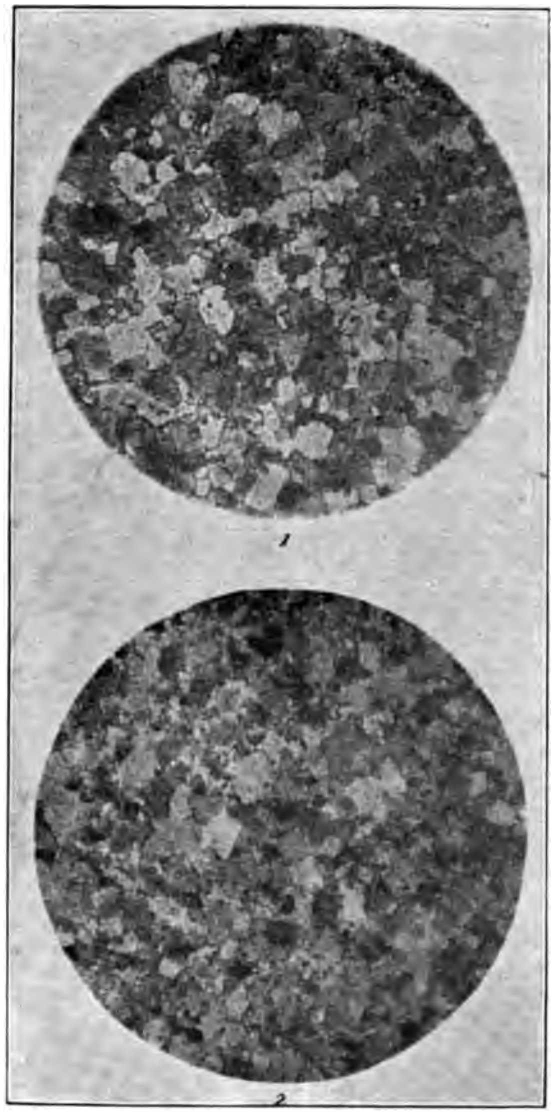
Thin sections of sandstone.

EXPLANATION OF PLATE IX

FIG. 1.— Section No. 4736. (× 12.) Dolomitic limestone from Duck Creek. This figure is an excellent illustration of the way in which the individuals of the coarser crystalline limestones interlock.

FIG. 2.— Section No. 4726. (× 12.) Dolomitic limestone from Sturgeon Bay. This figure shows the close, compact character of the crystalline dolomites, which accounts for their low percentage of pore space, and partly for their high crushing strength.

JOUR. GEOL., VOL. VIII, NO. 6 Plate IX



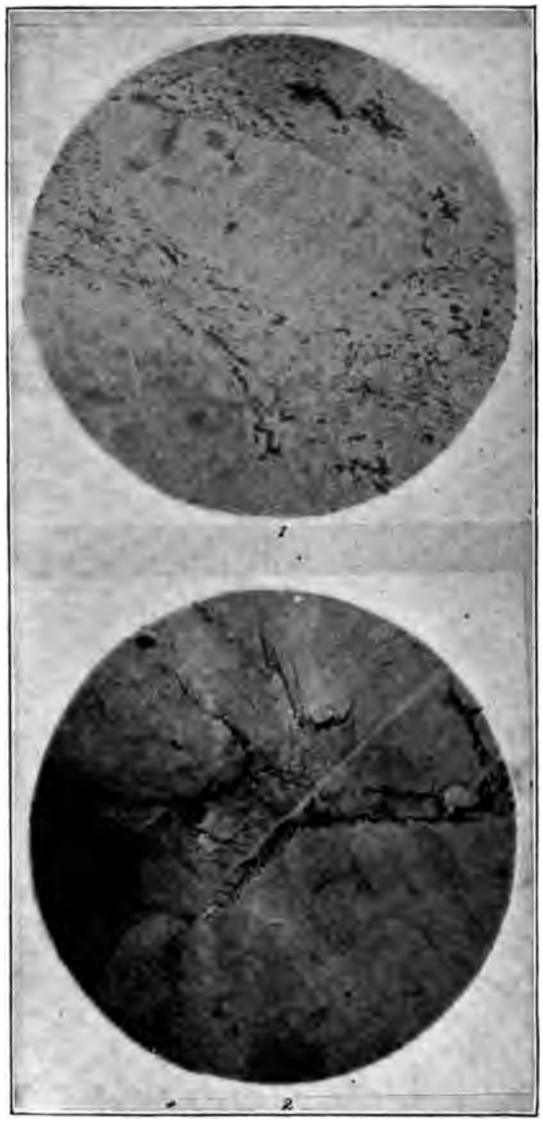
Thin sections of limestone.

EXPLANATION OF PLATE X

FIG. 1.—Section No. 4733. (× 12.) Berlin rhyolite. This figure shows the exceedingly fine grained matrix and the porphyritic individuals of feldspar, which are characteristic of the rock in the hand specimen. The mica which occurs in small flakes is also nicely shown. The parallel arrangement of the small flakes, which is evidently a cause for the "rift" in the rock, is well brought out. The cracking of the feldspar, referred to in the text, is also seen in this figure.

FIG. 2.—Section No. 4704. (× 12.) Utley rhyolite. Porphyritic crystals of quartz and feldspar and a small portion of the fine, dense matrix are shown in this figure. The compactness of the rock, with the consequently minute pores and low porosity are very evident.

JOUR. GEOL., VOL. VIII, No. 6 Plate X



Thin sections of rhyolite.

EXPLANATION OF PLATE XI

FIG. 1.—Section No. 4702 (× 12). Granite from Waupaca. This rock contains a greater variety of minerals than No. 4711. Besides quartz and feldspar there is an abundance of chlorite, epidote, and, in some places, biotite. The individuals are interlocking, but less regular than in many granites.

FIG. 2.—Section No. 4711 (× 12). Granite from Granite Heights. The dark colored parts are feldspar, and the lighter colored are quartz. This section illustrates nicely the close, interlocking character of the different individuals which contributes largely to the strength of the rock.

Thin sections of granite.

of the samples that it broke into fragments not much larger than the individual grains. The granites having medium sized grains flaked off at the corners when cooled moderately fast. The fine grained granite, such as the Montello, developed cracks through the middle of the sample. The different ways in which the granites were cracked and broken are illustrated in Plate V.

In contrast with the limestone and granite, the sandstone was to all appearances little injured by the extreme heat. Samples which were taken from the muffle furnace and allowed to cool gradually appeared to be uninjured, but after they had cooled one could crumble any of them in the hand almost as easily as he could the most incoherent sandstone. In fact, some of the samples when heated to a temperature of 1500° F. became so incoherent that after they had cooled they could scarcely be picked up without falling into sand. A person might be easily deceived as to the injury occasioned by extreme heat on sandstone. The samples often look as fresh and clean as when first quarried and, unless tested with the hammer, one would never suspect that the strength was so largely gone.

In general, the temperature tests indicate that there are few if any stones, whether they be granite, limestone, or sandstone, which will effectually withstand for a moderate length of time a temperature of 1500° F.

MICROSCOPIC TESTS

Thin sections of the more important building stones which were otherwise inspected were examined under a compound microscope. The microscopic examination reveals clearly the texture, composition and finer structures of the rock. These, combined with the field observations, furnish abundant data from which a person familiar with microscopical studies can estimate both the strength and durability of a stone.

The irregular interlocking character of the grains composing the igneous and finely crystalline rocks give evidence of strength which far exceeds that displayed by the sandstones composed of rounded grains which are held together by occasional patches of

ferruginous or siliceous cement. Each sample by itself has peculiarities in texture and composition which either add or detract from the strength and durability of the stone.

Plates VII, VIII, IX, X, and XI, with the accompanying explanations, illustrate the character of several of the Wisconsin building stones and the elements which contribute to their strength and durability.

E. R. BUCKLEY.

Reviews

Glacial Erosion in France, Switzerland, and Norway. By WILLIAM MORRIS DAVIS. Proc. Bos. Soc. Nat. Hist., July 1900; 49 pp., 7 figures, 3 plates.

In this admirable essay Professor Davis gives cogent reasons for modifying his former views relative to the efficiency of glaciers as erosive agents. A gradual change from a former conservative opinion which had been in progress in recent years was greatly accelerated by his studies in the Alps, Norway, and France during the past year. These studies lay along those topographical lines which Professor Davis had cultivated for the past two decades with such eminent success. They centered on the great discordance which he observed between the main and the tributary valleys when the former have been occupied by ice streams and the latter have not, or at least have not been effectively modified by glaciers. The tributaries in such cases have been styled by Gilbert "hanging valleys" because, instead of joining their primaries on well-adjusted normal gradients, they enter high up on the side walls. The tributary streams cascade down an abrupt declivity in entering the main glaciated valley in a manner quite out of harmony with their normal behavior within the tributary valleys above or in the glacial valleys below. Associated with the topographic break between the tributaries and the glacially worn primaries there are contrasted physiographies that point, as it seems to the author, and to the reviewer as well, unequivocally to the origin of the phenomena. In the tributary valleys, although in Pleistocene times they were involved in the general glaciation of the region, in some measure at least, the characteristic configuration of weathering and of water erosion clearly predominates, while in the main valleys, which have been the chief channels of glacial movement, flat bottoms and precipitous sides, bearing the peculiar aspects of glacially worn troughs, prevail. No observant traveler in Switzerland has failed to note the numerous small streams that cascade down the abrupt walls of the glaciated valleys. The numerous falls of Aar Valley, especially

that portion immediately below the Unter-Aar glacier, is a familiar and striking example.

Although these phenomena have long been noticed and some appreciation of their signification has been felt, it remained for a master in modern physiography to see and to set forth their fuller meaning. It is assumed that in the pre-glacial times the tributaries joined the trunk streams in the normal way with well-adjusted gradients, and that the discordance now shown is the result of the superior erosion of the trunk valleys by the glacial tongues that occupied them. The amount of the discordance is, therefore, taken as a rough measure of the superior erosive efficiency of the glaciers. In the Alps this is recorded in hundreds of feet, and in Norway it reaches into the lower thousands, and gives an impressive illustration of the erosive power of glaciers.

There are, however, several qualifications to be applied to this rough measure, and these are rather more complicated, and perhaps more important, than one might apprehend from reading the paper, though they do not seriously affect its method or its conclusions. In the broadening of the main valley by glacial erosion the mouths of the tributaries were cut back and the present points of intersection lie at higher levels than the original axis of the main valley. This is theoretically restored by projecting the gradient lines of the tributaries till they meet in the center of the main valley. For the main purposes of a general view, such as is sought by the paper, it is, doubtless, sufficiently near the truth to project the present lines of the tributary valleys without modification, but in stricter studies it is necessary to recognize the changes which the tributary valleys have undergone while the main valleys were being deepened by glacial erosion.

If unobstructed erosion was in progress in the tributary valleys while the main ones were being excavated by glaciers, the discordance between the two at the close would measure the *difference* in the rates of erosion of glaciers and of ordinary agencies, and a plus correction would be necessary to secure the absolute glacial erosion. During a part of the glacial period the tributary valleys were smothered in a general mantle of ice and suffered glacial modification as well as the main valleys, but not in just the same way. The main valleys lay in the chief direction of ice movement, for they determined it. The tributaries in the main lay more or less athwart the ice movement. They must hence be presumed to have suffered more or less of rasping

down of their rims and of filling up of their axes, and they thus assumed lower reliefs and flatter lines. The projection of their lines thus modified would not accurately represent the true preglacial lines. If the general glaciation sustained a large ratio, dynamically speaking, to the local or valley glaciation, this modification might introduce an error of some moment. As a matter of fact, however, judging from what we know of the general glaciation of the Alps, it probably was not very material. It is less easy to say what may be true of Norway, where general glaciation was much more important both actually and relatively.

In the advancing and retreatal stages of the several glaciations another group of influences came into play. The main valleys were filled by glacial tongues which more or less effectually blocked up the mouths of the tributaries, checked erosion in them, and induced filling, as may be seen in many such valleys today in the Alps, in Greenland, and elsewhere. The valley occupied by the Märjelen See may be cited as a familiar and striking example. While the mouths of the tributary valleys were thus blocked up, their rims were being degraded and a change was thus being wrought in their configuration. The effect of this class of action was to give the tributary valleys not only gentler declivities than they had preglacially, but gentler even than they would have acquired in the natural degradation of the basin had it remained open and free from ice throughout. The result may be styled a premature maturity, for it was not strictly normal to valleys at such positions in the general drainage system. It was a maturity of a local nature hastened by the establishment of a transient base-level at the mouths of the tributaries by the obstructing ice.

This special phase of the reshaping of the tributary valleys, being of the erosive type and being aided by the special climatic conditions of the time and by the high declivities of the valley sides, doubtless quite rapidly removed the signs of the previous subduing effects of general glaciation and restored an aspect resembling the preglacial one without being such, and hence made it difficult to distinguish this pseudo-maturity, if it may be so called, from such degree of maturity as had been attained in preglacial times, or, if you please, such an ideal stage of maturity as would have been reached by subærial erosion had not glaciation interfered. A restoration of the preglacial conditions of the main valley based on the lines of this pseudo-maturity of the tributaries would obviously involve error. Its amount depends on

the value of these phases of action, and that in turn is dependent on the duration and complexity of the glacial period.

A strict discussion is constantly vexed by the question whether the competency of the glaciers to erode is to be measured by the absolute amount of work done by them during their existence, be it longer or shorter, or by the ratio of the work they do to that which would be done by the usual erosive agencies in the same area and for the same time. Are we trying to determine the absolute or the relative? The latter is probably the truer basis of estimation in general, but both have their special values.

In the case in hand, such degradation of the tributaries at their mouths as took place during the period of glaciation lowered the base of reference by which the glacial erosion is measured, and a plus correction is required to give its absolute amount as already indicated. The lowering of the gradients and the premature flattening of the tributary basins, if uncorrected, leads to an erroneous projection of lines across the valleys and requires a negative correction in absolute measurement, and a more complicated and serious correction in relative measurement.

These suggestions do not cover the whole case, but they go as far as is perhaps permissible in a review, indeed, not unlikely farther than is warranted in the review of a paper based on fugitive studies that do not claim an exhaustive character. The importance, or otherwise, of the qualifications suggested depends much upon the duration and the fluctuations of the glacial period and the ratio of the general glacial action to the local valley phases.

If there is any reference in the paper to similar discordances between main valleys and tributaries not in any way connected with glacial erosion, it escaped the eye of the reviewer. Such cases of declared form exist and might naturally be expected to find at least passing recognition in a paper founded on discrepancies of this kind, the more so because in this neglected class also the main valleys are discrepantly broad and deep and the tributaries cascade down into them not unlike those described in the paper, though much less strikingly. Probably the neglected case has little application to the Alpine valleys discussed, and perhaps only an unimportant application to those of Norway. The case referred to arises from changes of drainage, whereby large volumes of water are thrown into valleys that had previously carried much less; such cases, for example, as the Upper

Ohio and the Upper Missouri. In these cases the great accessions of water have broadened and deepened the main channels out of all concordance with their tributaries. These at some distance back from the trunk streams run in their old valleys slightly modified, but as they approach the main valley, they rush down through new gorges, not, indeed, as steep and picturesque as those of the Alps or of Norway, but of like type. These have for some time been distinctly recognized, and are in constant use as working criteria in discriminating earlier and later systems of erosion, involving changed conditions. (See "Further Studies of the Drainage Features of the Upper Ohio Basin," Am. Jour., Sec. XLVII, April 1894, pp. 261–262.)

It seems to have been demonstrated that in Norway the glacial summit was some distance east of the present topographic divide and that hence the Norwegian valleys were called upon to carry away an amount of drainage greater than that which normally belonged to them in preglacial times. This took the form of ice at certain stages, and of water issuing from the edge of the ice field at other stages. How far this may have contributed to the observed result it is hard to guess without knowing more of the detailed history of the glacial period in that region, but it illustrates the connection of this mode of origin of discrepancies between trunk streams and tributaries with similar discrepancies of a true glacial origin. It is probable that even in the Alps, partly by topographic modification and partly by superior condensation, glaciation has concentrated an exceptional amount of drainage in the trunk valleys.

It is not probable, however, that any or all of the modifications herein suggested, or any others, seriously affect the representative truthfulness of the rough estimate of the superior erosive power of glaciers founded on discordance between the tributary hanging valleys and the glaciated trunk valleys. The paper is a valuable contribution to the doctrine of glacial erosion, and is likely to be the more influential with those holding opposite views because it comes from one who has heretofore held a conservative position on the subject.

The reviewer does not, on first reading, sympathize fully with the effort of Professor Davis to extend the analogy of river erosion so unreservedly to glacial work as done in the paper. The analogy is truer in gross externals than in refined analysis. A river erodes by virtue of its pressure and momentum, scarcely at all by rigidity. Very largely its work is done by the striking force of particles driven rapidly

against the valley walls and bottom, or against each other. This is largely true even of the pebbles rolled on its bottom, as anyone may see by examining the nick-marks that cover their surfaces and that sharply distinguish them from glaciated pebbles, or by critically comparing a waterworked surface with a glacially worn surface.

On the other hand a glacier does its work by virtue of its rigidity and pressure, and scarcely at all by its momentum, for its velocity is very low. A river with the same velocity as a glacier would be almost absolutely inert as an abrading agency. In the judgment of the reviewer no one is entitled in the present state of evidence to assume that the laws of fluids control the action of glaciers except in external similitude, which is due to the fact that gravitation is the dominant factor in both cases. In convenient and popular exposition the similitude has many advantages, but in framing scientific doctrine and nomenclature, and still more in mental procedure, it is attended by danger. It is doubtless as important to avoid the similitude in critical work as it is permissible to use it in easy exposition.

T. C. C.

Bartholomew's Physical Atlas: An Atlas of Meteorology. Vol. III. A series of over four hundred maps. Prepared by J. G. Bartholomew, F.R.S.E., and A. J. Herbertson, Ph.D., and edited by Alexander Buchan, F.R.S. Under the patronage of the Royal Geographical Society. Edinburgh, 1899.

This is the first volume to appear of what promises to be an epoch making work in scientific geography. The entire field of physical geography is to be covered by seven volumes. The plan was furnisht by the famous *Physikalischer Atlas* of Berghaus, tho the field is vastly extended, and it will make a work when completed, perhaps ten times the size of the German atlas.

This great venture is preparing under the direction of J. G. Bartholomew, revised and edited by a corps of eminent specialists, in volumes as follows:

I. Geology — Sir Archibald Geikie.
II. Oceanography — Sir John Murray; and
   Orography — Professor James Geikie.
III. Meteorology — Alexander Buchan,
IV. Botany — Professor Bayley Balfour.

V. Zoölogy — P. L. Sclater.
VI. Ethnography — Professor A. H. Keane; and
Demography — Professor Elisee Reclus.
VII. Cosmography — Professor Ralph Copeland; and
Magnetism — Professor C. G. Nott.

It is now about half a century since the appearance of a great English work along these lines, that of Dr. Keith Johnston, based on the *Physikalischer Atlas* of Dr. Heinrich Berghaus (1837–1852). The original German publication is justly regarded as a landmark in the history of geography, and has been kept at the forefront of high art in cartography by his nephew, Dr. Hermann Berghaus, who brought to his aid some of the most famous German scholars, such as Hann, Neumayr, Zittel, and others. This is the work which has been such an inspiration to the students of geology and geography in the present generation, and this atlas it is which has furnisht the plan for the greater Scotch work now in preparation. To quote from the prospectus:

Recent years have marked a great and rapid development in the field of scientific geography. The additions to our previous knowledge have been numerous and important, but they are scattered throughout hundreds of publications, in various languages, they are difficult to find, and known only to specialists in each department. Hence there is a need for a work embodying in concrete and graphic form a digest of all this scattered material — a new physical atlas.

So some years ago the enterprising Scotch firm obtained copyright privileges on the material in the Berghaus plates, and planned at much larger work, one of over two hundred plates, compiled from sources liable to be of more immediate interest to English and American students, getting the heartiest coöperation from the world's greatest specialists along all the desirable lines; ten years have already gone to the preparation of the most comprehensive work of the kind ever attempted. The cost of production alone will reach a half million dollars.

Curiously enough meteorology, the youngest of the physical sciences, is so far advanced in the accumulation of data from very wide areas of the earth's surface, that it is in the most forward condition of all as to the possibility of charting complete data. Mr. Alexander Buchan makes this rather startling statement:

If the present state of the science of meteorology as regards the geographical distribution of results be compared with that of the other sciences such as

geology and the biological sciences, it stands second to none. None of these sciences can show such a world-wide distribution of precise results as are collected in this atlas of meteorology, in illustration of the geographical distribution of temperature, pressure, humidity, cloud, rainfall, and movements of the atmosphere, with illustrations of their influences over, and interrelations with, each other.

Dr. Hann's *Atlas der Meteorologie* was the first attempt to chart systematically the data of the science. His atlas, as found in Berghaus, has twelve plates, giving about sixty maps. And, altho this has been brought down to 1887, there has been a very great advance in all lines of the science since then, and the time is ripe for a more complete publication. A mass of widely scattered observations from all over the world is now charted for the first time.

The 400 maps of this atlas of meteorology are groupt under the two heads of Climate and Weather. The climate maps summarize the great mass of observations, first for the whole world, next for more detailed study of regions specially rich in observational data. There are monthly and annual charts for the elements of climate — temperature, pressure, winds, cloud, sunshine, and rainfall. The weather maps show the most characteristic weather types for given periods over defined regions.

Preceding the charts there is a general introductory article, and a special discussion of each chart. This will be of the highest value to students of climate and the weather. Appendices give complete lists of all the meteorological services, with all the stations and publications. The frontispiece consists of a graphic charting of the areal distribution of observations over the earth, in which India, Europe, and the United States stand out conspicuously in their dark shading. The volume closes with a glossary of terms, and a critical bibliography, classified for all lines of research in the subject, both of which will be very helpful.

The magnitude of the undertaking of the preparation of these charts, and the accuracy we are here dealing with will be better realized when some plain statement of the figures is made. The total number of meteorological stations is, in round numbers, 380 of the Order I; 2620 of the Order II; 6600 of the Order III, and of Rainfall, 19,400; total, 29,000; special stations for crop reports will bring the grand total up to about 31,000.

The general temperature charts are based upon fifteen years' observations from 1539 stations. The general pressure charts from fifteen years' observations at 1280 stations. These reports are the summaries of about 17,000,000 observations for temperature, and about 14,000,000 for pressure, and this is excluding all observations at sea.

The charts of the first part under the general heading Climate, are classified under the headings:

I. Isotherms.
II. Isobars and wind arrows.
III. Isotherms and Isobars month to month.
IV. Isohels, the year's sunshine for Europe and North America.
V. Isonephs, distribution of cloudness over the globe.
VI. Isohyets, annual, seasonal and monthly rainfall over the globe.
VII. Maps of hyetal regions and seasonal distribution,
VIII. Isobars and Isohyets; rainfall as related to pressures.

The second part on Weather, has charts classified as:

I. Abnormally cold and hot seasons and months.
II. Pressures as related to wind in type storms.
III. Pressures as related to types of wind and weather.
IV. Storm tracks and storm frequency.
V. Type deviations from normal pressures.

The first chart in the volume shows the world's isotherms on Mercator's projection, in which the relief of the land is shown by line shadings in black. Contours of 600, 3000, 6000, and 12,000 feet are shown, and similar contours in the oceans represented by fine dotted lines. Even the little 3 × 6-inch insets show all highlands over 3000 feet by shading. This plate and No. 11, the world's isobars, are equally beautiful, and are the finest plates in the book. It will be no exaggeration to say that no more beautiful plates have ever been engraved. They are magnificent in accuracy, neatness, completeness and beauty of engraving, nor are the lesser maps less beautiful, they are merely smaller, and chart less complex data as a rule. One is struck, too, by the artistic range of coloring. The tints show with a sufficient contrast the varying values of the data charted, yet there is not a harsh note in the whole book.

Two of the most beautiful plates in the book are the charts of the monthly isotherms of the British Isles, and another of the monthly isobars and isohyets.

In all the maps the English measurements are given, and in each case their metric equivalents — the pity of it, that we need to record in two systems!

It almost seems like caviling to offer any criticism on so sumptuous a work. But there are some shortcomings. In only one case is the projection used named; it would have been an agreeable addition, had the projection been specified for all maps of lesser area, and in all such maps a horizontal scale should be given, either in arithmetical ratio, or by linear representation of miles and kilometers. There is scarcely a scale in the book.

In all maps of isohyets the very important element of altitude, it would seem, is almost a necessity for the proper interpretation of the rainfall, yet on Plate XXI, the principal plate of isohyets, there is no attempt to show altitudes, even in the larger areas of Europe and the United States. The lack of contours and the scale in such insets as Jamaica, Japan, Java, and Mauritius is a serious fault. Even in Plate XXIV in the large scale map of isobars and isohyets of the United States and Canada, only the one contour of 3000 feet is shown. Here, far more than in the general maps of Plates I and II, are the several contours needed. It may be, of course, that in some cases, for example, the India map, the relief was omitted to prevent overloading. And true it is, that with all the mass of data entered in these maps, there is never in any of them a lack of legibility.

But after all the flaws are found, they are not very serious, they are mere spots on the sun. The work will long stand as a monument to very high ability in meteorology and cartography.— J. PAUL G.

Mineral Resources of Kansas, 1899. By ERASMUS HAWORTH, Univ. Geol. Surv. of Kansas, Lawrence, May 1900; pp. 67, 4 plates.

This is the third of the annual bulletins on the mineral resources of the state which the University Geological Survey of Kansas is issuing, and is worthy of note as a laudable effort on the part of an educational institution of high grade to convey to the people, without distinction and without charge, commercially valuable information gathered under scientific auspices. Is is one of the many current indications of the breaking down of the narrow limitations that have so long hedged in the traditional institution of learning to its infinite

harm, and of the broadening and elevation of the functions of universities in the true sense of these adjectives, for an institution is broad in proportion to its contact with the full range of serious thought and with all classes of its natural constituency, and it is elevated in proportion as it is really useful, the notions of the leisure classes to the contrary notwithstanding.

The general summary shows an annual production of nearly 39 million dollars of which, however, a part appears to be the smelting and refinement of ores mined outside the state. The record shows that all the mineral industries felt the impulse of the country's general prosperity. The coal production reached a value of over five million dollars. The plaster, hydraulic cement, clay, salt, and stone industries all exhibit marked advances. Altogether it is a good showing for a state whose great industry is agriculture.

T. C. C.

Results of the Branner-Agassiz Expedition to Brazil.

I. *The Decopod and Stomatopod Crustacea.* By MARY J. RATHBUR. 23 pp., 1 plate.

II. *The Isopod Crustacea.* By HARRIET RICHARDSON, 3 pp., 4 figures.

III. *The Fishes.* By CHARLES H. GILBERT, 23 pp. 1 plate.

IV. *Two Characteristic Geologic Sections on the Northeast Coast of Brazil.* By. J. C. BRANNER, 17 pp., 5 sketch maps and sections, Proc. Wash. Acad. Sci., August 1900.

Nos. I, II, and III relate to existing forms of life, and belong to that realm of current geology which we conveniently, and doubtless wisely, leave to the zoölogists.

No. IV gives in as much detail as field circumstances would permit two sections opened by railways running from the coast toward the interior, and traversing the border formations somewhat nearly normal to their strike. The section along the Bahia and Minas Railway lies at about 18° S. Lat., and that along the Alagôas Railway between 9° 20′ and 9° 40′ S. Lat., the two sections being about a thousand kilometers apart. They show essentially the same structure : a series of relatively young sediments lapping back over old crystalline rocks. The age of the sediments is open to question, and the problem is regarded as too large for specific discussion in the paper. The evidence is thought to point to the following conclusions :

1. The Bahia basin, formerly referred to the Cretaceous, is probably either Eocene Tertiary, or Laramie.

2. The parti-colored beds along the coast, formerly referred provisionally to the Tertiary, are the same as the Bahia Eocene.

3. The sediments of the Alagôas section are of fresh-water origin, like those of Bahia.

4. No fossils have been found in the section along the Bahia and Minas Railway, but it seems probable that these beds are the southward continuation of the Bahia beds.

The crystalline series next back of the sedimentary beds consist mainly of quartz-monzonites (gabbros) granites and gneisses, the first having a notable development. The Bahia-Minas section ends in mica and other schists much faulted, wrinkled, and cut by veins, and much more deeply decomposed than the quartz-monzonites.

The contribution is doubly valuable in that it bears on the evolution of a continent that has played a peculiar and interesting part in geologic history, but which is as yet too little known to be interpreted with precision or satisfaction. The generosity of Agassiz, as well as the devotion of Branner, in securing it are to be gratefully recognized.

T. C. C.

Progress of Geological Work in Canada During 1899. By HENRY M. AMI, Can. Rec. of Sci., Vol. VIII, No. 4, July 1899.

Contrary to the natural interpretation of the title this is a list of works relating to Canadian geology published during the year 1899 through various avenues, and embracing private as well as official works. It will be found helpful to working geologists.

C.

Descriptive Catalogue of a Collection of the Economic Minerals of Canada, Paris International Exhibition, 1900.

This is somewhat more than a simple descriptive catalogue of the minerals exhibited, as it contains notes relative to the modes of their occurrence and to the industrial operations connected with them, when these are important, as well as other incidental information which gives the catalogue value as a book of reference.

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DE LA COOPÉRATION INTERNATIONALE DANS LES INVESTIGATIONS GÉOLOGIQUES[1]

On a reproché à la Géologie, et ce reproche a surtout été fait par les personnes versées dans les sciences exactes, de se contenter de mesures approchées et de baser ses conclusions sur des notions parfois discutables. Il ne faut pas s'émouvoir outre mesure de cette critique ; la précision mathématique ne paraît pas conciliable en effet avec notre connaissance actuelle de la nature des choses; nous ne les pénétrons encore que d'une façon approximative, et c'est sagesse à nous, de nous garder de conclusions rigoureuses trop absolues, quand notre raisonnement ne repose que sur des prémisses insuffisamment établies.

Depuis un siècle, de louables efforts ont été tentés pour faire entrer la géologie dans la voie des sciences expérimentales, des sciences exactes. Nous devons une grande reconnaissance à James Hall qui ouvrit la voie, et à tous ceux qui l'ont suivi, et parmi eux, aujourd'hui que nous sommes en France, réunis à Paris, c'est vers Daubrée, le maître et l'ami distingué, que remontent nos pensées ; car sa place est marquée pour toujours, dans nos annales, comme celle d'un des grands pionniers de la géologie expérimentale.

[1] Presented to the eighth session of the International Geological Congress, Paris, August 1900.

Beaucoup a été fait sans aucun doute déjà pour soumettre les faits observés à des mesures précises, et pour les contrôler expérimentalement dans les laboratoires, mais il serait puéril de ne pas reconnaître qu'il reste encore beaucoup plus à faire. On peut même prévoir que c'est de ce côté que se produiront les découvertes les plus fécondes, les progrès les plus décisifs. Jusqu'ici, les efforts tentés ont été individuels, exécutés indépendamment par des savants de divers pays, marchant parallèlement dans la carrière, sans profiter, ou sans s'aider, de ceux qui travaillaient à côté. Aujourd'hui nous nous demanderons s'il ne serait pas opportun d'envisager la possibilité d'une entente, l'organisation d'une coopération internationale plus large et systématique, dans cet important domaine de recherches scientifiques ? Et il nous semble que les Congrès géologiques internationaux soient naturellement indiqués pour faire aboutir pratiquement et assurer le succès d'une tentative de ce genre.

C'est une voie un peu nouvelle pour nos Congrès, mais pas complètement neuve cependant. On trouve en effet, déjà, dans leur passé, cette même tendance à une coopération méthodique des investigations géologiques ; tels sont la création de notre Comité de la Carte géologique d'Europe, notre Commission des Glaciers et celle de l'Observatoire flottant. L'idée a déjà été lancée, puisque nos commissions fonctionnent ; mais nous croyons qu'elle peut être généralisée et devenir d'une grande fécondité. Déjà l'an passé, à Douvres, dans mon discours présidentiel, devant la section géologique de l'Association Britannique pour l'Avancement des Sciences, et dans une occasion où les géologues anglais avaient le plaisir de recevoir un si grand nombre de leurs confrères de France et de Belgique, j'ai touché cette question, et exprimé l'espérance de la porter cette année devant le Congrès géologique international réuni à Paris. C'est ce projet que je réalise aujourd'hui, en vous soumettant les remarques qui suivent. Il m'a semblé que nulle occasion ne serait plus favorable que celle-ci, où tant de géologues, délégués de tous les points du globe, se trouvent réunis, pour parler au Congrès de son but même, et de la direction à donner à ses efforts pour développer sa bienfaisante

influence et servir la cause de la science à laquelle nous avons consacré nos vies. Le Congrès, en raison même de son caractère international, a les moyens, mieux que toute administration, d'organiser et de guider les recherches géologiques; et on peut affirmer que s'il est possible d'aboutir pratiquement dans cette tentative de coopération et de coordination, on le devra au Congrès qui l'encouragera et la patronnera.

Dans l'état actuel de nos connaissances, nul ne peut travailler dans le vaste champ de la géologie dynamique, sans reconnaître la nécessité impérieuse et croissante d'un plus grand nombre de mesures de précision, sans souhaiter des recherches expérimentales rationnelles; par là, cet important chapitre de la géologie gagnerait en précision et en exactitude, et son progrès serait assuré. On a déjà beaucoup fait dans cette voie, il est vrai, mais mon sentiment néanmoins est que la géologie expérimentale en est encore à ses débuts. Nous ne devrions avoir de trêve, que tous les phénomènes géologiques susceptibles de ce genre d'investigations, n'aient été mesurés avec précision, ou expliqués par des expériences de laboratoire. Trop souvent, et dans les diverses branches de la géologie, nous nous contentons de l'observation plus ou moins précise et exacte sur le terrain, quand nous pourrions la contrôler et étendre sa portée par des déterminations précises, par des données numériques, qui fourniraient des bases exactes aux déductions théoriques et pratiques.

Mais le sujet ainsi compris est trop vaste pour être envisagé ici dans son ensemble. Je me bornerai à quelques examples pris dans les deux grands groupes de phénomènes de la dynamique géologique: ils me permettront d'arriver à mon but.

Voyons d'abord les mouvements et changements qui s'accomplissent à l'intérieur du globe, et qui sont généralement désignés comme *hypogènes*. Il est évident que beaucoup de ces phénomènes pourraient être observés et enregistrés avec plus de soin et de régularité qu'on ne l'a fait jusqu'ici. Les recherches du professeur George Darwin, et d'autres auteurs, ont appris combien étaient constants, bien que petits, mais mesurables, les tremblements auxquels la croûte terrestre était assujettie. On

doit se demander si ces trépidations sont en relation avec quelque lent déplacement de la croûte terrestre, et dans ce cas, quelle est leur résultante sur le niveau de la surface, dans l'intervalle d'un siècle ?

Un autre fils de l'illustre Darwin a établi récemment un appareil enregistreur sur l'une des lignes de dislocation du sol du sud de l'Angleterre, cherchant à constater s'il se produisait des mouvements du sol, de l'un ou l'autre côté de cette ligne de division. Des instruments de ce genre seraient avantageusement installés dans d'autres pays, notamment dans les régions affectées d'importantes failles récentes. Il serait important et intéressant de reconnaître si, à la suite d'un tremblement de terre, il s'est produit quelque dénivellation, de part ou d'autre d'une de ces failles.

Les tremblements de terre ont été l'objet de nombreuses études, et cependant il s'en faut beaucoup que nous possédions une explication suffisante et adéquate de la cause du phénomène. Dans la plupart des cas, d'ailleurs, ils n'ont été étudiés que lorsqu'ils avaient cessé de se faire sentir ; et l'installation d'appareils enregistreurs, de séismographes, a donné une clarté et une précision nouvelles à nos conceptions concernant la nature de ces mouvements. Ces observations, toutefois, ne pourront donner de résultat satisfaisant que lorsqu'elles auront été poursuivies sur de vastes espaces et pendant de longues périodes. Déjà l'Association Britannique pour l'Avancement des Sciences a fondé une Commission Séismologique ; ses instruments enregistreurs fonctionnent en plusieurs parties du monde et servent la science, sous l'inspiration de M. Milne. Le Japon a déjà fait beaucoup dans cette voie et nous sommes fondés à attendre de nouveaux services du Survey Vulcanologique, dirigé par le professeur Koto. Le Congrès géologique international pourrait voir s'il ne serait pas possible d'installer un autre Survey semblable, en quelque autre pays exposé aux tremblements, et il pourrait chercher à unifier les observations relevées dans les divers pays ; il fournirait de la sorte un fonds solide et bien documenté à toutes les dissertations sur les tremblements de terre.

Les relations des tremblements de terre avec la formation des montagnes sont également susceptibles d'être élucidées par des mesures exactes. Les secousses séismiques, si frequentes suivant les chaînes de montagnes, doivent-elles être considérées comme la continuation et la suite des processus qui ont déterminé la formation de ces chaînes ? Et ces déplacements, dans quel sens s'opèrent-ils, ont-ils pour résultat un mouvement d'élévation ou d'affaissement ? Nous ne pouvons actuellement répondre à ces questions, mais leur solution se présentera d'elle-même, le jour où nous aurons soumis les phénomènes séismiques à des mesures précises. Des mouvements et déplacements, insensibles à l'œil de l'observateur, seront mis en évidence par des séries répétées de mesures d'altitude minutieuses, au dessus d'un repère bien choisi. Ces chiffres s'ils étaient d'une exactitude absolue, permettraient par exemple de déterminer, s'il s'est produit, en quelque point, un changement d'altitude, après un tremblement alpin. Avec de semblables données, nous serions en mesure de fixer si la grande ride terrestre des Alpes, continue encore à s'élever ou si au contraire elle s'abaisse, et nous pourrions indiquer la vitesse du mouvement. Si ces mouvements sont lents, trop lents pour être appréciables aux sens de l'homme, depuis qu'il observe, c'est une raison de plus pour les mesurer exactement, comme des phénomènes continués pendant des périodes immenses.

Ces mesures ne nous apprendraient pas sans doute si les chaînes de montagnes sont nées dans une convulsion gigantesque, ou si elles se sont dressées en plusieurs fois, par des soulèvements répétés, ou enfin si elles se sont élevées tranquillement d'un mouvement lent et continu ? Mais elles nous mettraient au moins en possession d'informations suggestives, sur la vitesse des mouvements d'oscillation de la croûte terrestre.

D'autre part, il est bien certain que le genre d'observations nécessaires pour obtenir ces résultats ne saurait être une œuvre personelle. Pour l'entreprendre et pour aboutir, il faudrait s'assurer le concours d'un ensemble de collaborateurs espacés sur toute la longeur et sur les deux versants d'une grande chaîne

montagneuse. Leurs observations devraient se poursuivre suivant un plan uniforme, méthodique, convenablement mûri, qui laisserait à chacun l'indépendence de ses efforts individuels, mais assurerait la communauté de but. Il nous paraît que l'organisation et le contrôle d'une entreprise de ce genre fournirait un but élevé d'activité à un Comité du Congrès géologique international.

Il y a une autre branche de géologie dynamique, une autre série de mouvements hypogènes dont les Congrès internationaux pourraient encore s'occuper avec succès ; et j'ai ici l'assurance de mon expérience personelle. C'est la question souvent disputée de l'origine des cordons littoraux ou plages soulevées, si caractéristiques des rivages marins du N. W. de l'Europe. Les géologues sont toujours aussi divisés relativement à l'origine de ces terrasses remarquables ; certains y voient des preuves d'abaissement du niveau de la mer, d'autres les considérant comme démontrant le soulèvement du sol continental. Il semble cependant qu'on ait négligé jusqu'ici de déterminer la condition fondamentale et essentielle, nécessaire à la solution de ce problème : de bonnes mesures.

Sans doute, on a des mesures locales, suffisamment précises et exactes, du niveau de ces plages, mais elles sont isolées et disséminées ; elles devraient au contraire être généralisées et étendues à de vastes régions, pour permettre des conclusions définitives. Il faudrait ici lever une série de nivellements rigoureux des plages soulevées, en les repérant exactement sur toute leur étendue, relativement à la ligne des côtes.

Ainsi, par example, en Ecosse, il y a deux de ces terrasses bien marquées, l'une à l'altitude d'environ 50 pieds, l'autre à environ 100 pieds, au-dessus du niveau actuel de la mer. Ces deux terrasses se retrouvent à E. et W. sur les deux rivages du pays, paraissant conserver les mêmes altitudes ; or, on n'a point encore fait de nivellement systématique qui permettrait de reconnaître la constance ou la variation de leurs niveaux, soit d'un côté ou de l'autre du pays, soit dans la direction du N. au S. — Ces deux terrasses disparaissent l'une comme l'autre,

au Nord, on ne les voit pas non plus au Sud, en Angleterre; on remarque en outre certaines inégalités apparentes de niveau, suivant leur parcours, ce qui semble indiquer qu'elles ont été sollicitées par des mouvements inégaux. Mais avant que ces différences aient été mesurées avec précision, je n'estime pas qu'un savant soit fondé, d'après ce qu'on observe en Ecosse, à conclure que le niveau de la terre s'est élevé, ou que celui de la mer s'est abaissé. J'espère que cette question spéciale sera élucidée chez nous, d'une façon satisfaisante, et j'ai déjà pris des dispositions à cet effet; mais sa solution ne suffira pas pour asseoir une conclusion générale. Elle devra être étudiée comparativement dans d'autres pays. Il serait désirable que sous l'impulsion et sous les auspices des Congrès géologiques internationaux, les géologues danois, norwégiens, suédois, finlandais, russes, écossais, américains, entreprennent d'un commun accord un lever détaillé, qui fixe, d'une façon définitive, ce problème des lignes littorales de l'hémisphère boréal.

Je passerai maintenant à la considération de quelques exemples choisis dans l'autre classe de la dynamique géologique, parmi les *phénomènes épigènes;* là encore on trouverait de grands avantages à généraliser les méthodes préconisées de mensuration et d'expèrimentation.

L'ètude des phenoménes de dénudation nous ouvrira un champ illimité, quoique de toutes parts déjà il ait été défriché avec activité et avec succès. Des volumes, des mémoires, des articles de toute forme, ont été consacrés à l'étude de ces phénomènes de dénudation; et cependant, dans cette riche littérature, il y a pauvreté assez générale de précision, absence presque constante de résultats numériques, rareté des mesures exactes, systématiques ou continues, en un mot défaut habituel des données qui permettraient de se rendre un compte véritable de l'étendue et de la rapidité des dénudations observées. Il y a toutefois des exceptions honorables, et nous possédons bien quelques mesures exactes de la plus haute valeur, et leur nombre s'accroît encore tous les jours, mais quel avantage il y aurait, pour la science, à le décupler!

C'est qu'en effet quand on envisage la sculpture et les formes d'altération des traits terrestres sous l'influence de la dénudation, il semble qu'il y ait cent moyens de contrôler l'observation immédiate des phénomènes, par des mesures directes, ou par des expériences de laboratoire.

C'est presque un lieu commun de dire, en géologie, que la quantité de substances enlevées en suspension ou en solution par les cours d'eaux, mesure l'importance de la dénudation des régions drainées par ces rivières. Et cependant combien inégales, et combien insuffisantes en général sont les indications numériques que nous possédons sur cette importante question! On n'a encore étudié systématiquement, à ce point de vue, qu'un très petit nombre de rivières, et les résultats discordants ne peuvent être considérés comme définitifs. Ils ont suffi seulement à montrer l'intérêt et toute l'importance de cette méthode de recherche; mais on n'est pas encore en possession de documents suffisants pour en tirer des déductions rationnelles, moins encore des généralisations.

Ce qu'il nous faudrait pour cela, c'est une série d'observations bien menée, organisée suivant un plan uniforme, poursuivie pendant plusieurs années, et étendue à toutes les rivières d'un pays, voire même à toutes les grandes rivières des divers continents, loin d'être limitée à un seul cours d'eau. Il importerait de connaître, aussi exactement que possible, l'étendue et la surface du bassin des rivières, les relations de leur débit avec les quantités de pluie, le détail de toutes les conditions météorologiques aussi bien que des topographiques, les variations dans les proportions des matières suspendues ou dissoutes dans leurs eaux, relativement aux formations géologiques traversées, à la forme du fond, à la saison, au climat. En un mot, il faudrait connaître en détail le régime de toutes les rivières. On peut citer, comme modèle du genre, l'admirable rapport de MM. Humphreys et Abbott, sur les "Physics and Hydraulics of the Mississippi" publié en 1861, bien que ces auteurs, préoccupés de diverses questions étrangères à la géologie, aient laissé dans l'ombre certains points d'un grand intérêt pour nous.

Ce que nous avons dit de l'étude des Rivières s'applique exactement à celle des Glaciers. Il semble, il est vrai, que les lois qui régissent le mouvement des glaciers aient été amplement approfondies, et qu'on ait relevé avec soin leurs mouvements d'avance et de retrait. Mais ce sont des côtés de la question plus intéressants pour le physicien et le météorologiste. Nous, nous devons réclamer, comme géologues, des informations plus précises sur le labeur géologique des Glaciers. Il nous importe de mieux connaître la vitesse avec laquelle ils creusent leur voie, les circonstances qui favorisent ou retardent leur puissance érosive, les conditions qui leur permettent de remonter des pentes, et enfin la réalité et l'importance des mouvements, en sens divers, qui se produisent dans la glace, et par suite desquels les cailloux sont charriés et les stries sont orientées dans des directions variées. Ce sont autant de questions, et il en est beaucoup d'analogues, sur lesquelles nous ne possédons que des renseignements vagues et incertains. Il semble cependant que leur solution dépende d'une série d'observations systématiques, suffisamment prolongée, à condition qu'elles ne soient pas bornées à la Suisse, mais poursuivies en Scandinavie, dans les Régions arctiques et antarctiques, aux Indes, à la Nouvelle-Zélande. Notre Congrès International a déjà marché dans cette voie, et créé un Comité des Glaciers qui, sous l'impulsion enthousiaste de M. Forel, a déjà rendu des services signalés. Ce Comité est digne que nous nous intéressions à lui et que nous encouragions ses efforts, il y aurait avantage à le développer, pour qu'il étende son action à toutes les régions du globe accessibles aux géologues. Ainsi les savants danois qui, dans ces dernières années, ont tant ajouté à nos notions sur les glaciers et les nappes glacières du Groënland, les géologues américains qui ont fait de si bon ouvrage parmi les glaces de l'Alaska, seraient d'excellentes recrues pour notre Comité des Glaciers; et il y a lieu de croire qu'il suffirait d'une simple invitation pour qu'ils poursuivissent de concert avec nous, les mêmes recherches systématiques.

Un autre sujet d'étude qui a attiré à maintes reprises l'attention des géologues, est celui de la Dénudation Subaérienne de la

croûte terrestre. Et cependant nous manquons aussi de documents précis ; on n'a pas encore mesuré son action comparativement, avec précision et méthode, sur les différentes roches, et sous diverse climats. On pourrait s'aider dans cette mesure de l'examen de bâtiments, portant la date de leur construction ; j'ai pu ainsi indiquer, il y a déjà 20 ans, la rapidité de la désagrégation de certaines roches dans un climat humide et variable comme celui de l'Ecosse. On a cependant jusqu'ici peu fait, dans cette voie.

L'étude de la dénudation ne peut guère se séparer de celle de la sédimentation : les matériaux déposés par la sédimentation sont ceux qui on été enlevés par dénudation, moins ce qui a été dissous en route, dans les eaux des ruisseaux ou de la mer. Or, il nous reste beaucoup à apprendre sur les conditions de la sédimentation, et ses variations de vitesse.

Il ne semble pas qu'on puisse compter sur de notable progrès dans cette étude, aussi longtemps qu'on ne l'abordera pas systématiquement, au moyen d'un plan préconçu, bien mûri et poursuivi avec continuité. Il y a encore bien des inconnues pour nous, dans la forme et la rapidité des dépôts qui s'accumulent sous l'influence des divers facteurs, dans les lacs, les estuaires et la mer. Ainsi nous ne saurions indiquer par une moyenne, la vitesse avec laquelle se comblent les lacs des divers pays d'Europe. Si d'ailleurs nous connaissions cette vitesse, et si nous savions, d'autre part, la quantité de sédiments déjà amassée, nous aurions en notre possession un moyen de calculer, non seulement en combien de temps ces lacs seront comblés et disparaitront, mais aussi, ce qui est plus important, depuis combien de temps leur remplissage se poursuit. Ce chiffre en effet, nous fournirait une date, pour la fin de la Période Glaciaire. Des conclusions de cette nature ne sauraient découler d'observations isolées ou locales, elles doivent être basées sur les observations combinées de nombreux observateurs, des diverses régions lacustres du continent, suivant un plan déterminé.

La géologie est entrée dans une période où on doit attendre les plus grands avantages de méthodes d'investigation plus précises, de la convergence des efforts individuels, librement associés

sous une même règle, et vers un même but. Il serait aisé d'en multiplier encore les exemples. Mais nous croyons en avoir dit assez, pour faire voir au Congrès la portée de ces tentatives, et l'importance que nous y attachons. Nous ne proposerons pas toutefois ici de plan général d'organization, notre intention actuelle étant de nous borner à une sorte de consultation, et de demander à nos confrères s'ils pensent avec nous qu'il serait bon, avantageux, et praticable d'installer sur des bases plus larges la coopération en géologie? J'estime que nous aurions rendu un service durable à la science, si nous arrivions à grouper des observateurs en comités d'action, travaillant avec méthode, vers un but déterminé, soit l'un de ceux que je viens d'indiquer, ou tout autre. Il y aurait même de la prudence à débuter par la question la plus facile, celle qui réclamerait la moindre dépense d'hommes et d'argent. On pourrait partager la besogne, entre les divers pays représentés au Congrès. Chaque pays pourrait librement choisir le sujet de ses observations, n'étant poussé que par l'émulation de voir ses voisins avancer dans la même voie.

Un Comité Central composé de membres des diverses nations engagées dans ces recherches sur le terrain, rendrait des services en traçant les méthodes générales, les plans de travail, et en indiquant le but. Son rôle se bornerait à organiser le travail et à généraliser la méthode, en laissant la plus grande latitude possible aux efforts individuels.

La publication des résultats ne serait pas non plus soumise à l'appropriation du Congrès Chaque collaborateur, chaque comité resterait libre de suivre ses convenances, et on se bornerait à présenter à nos sessions, tous les trois ans, un aperçu sommaire des résultats généraux. Nous avons la confiance que ces résumés, publiés par nos Secrétaires et insérés dans nos Comptes-Rendus, constitueraient un des chapitres les plus importants de nos volumes triennaux. L'idéal d'une assemblée comme la nôtre ne saurait être de contrôler le progrès, mais bien de l'encourager, et de favoriser le groupement et l'association de toutes les initiatives internationales.

ARCHIBALD GEIKIE.

PROPOSED INTERNATIONAL GEOLOGIC INSTITUTE[1]

It is a source of profound regret that imperative circumstances prevent my attendance at what I am sure will be a most important session of the International Geological Congress. Forbidden this pleasure, I venture to show my interest by offering some suggestions relative to a line of effort tributary to the leading purpose of the congress. At the first session of the congress in 1878, which I had the pleasure of attending, a dominant theme of discussion was geologic classification, and this continued to be the foremost theme for subsequent sessions until it was found impossible to agree upon any system proposed. It furthermore developed that many of the most able and experienced geologists were of the opinion that it was premature to attempt any authoritative action in the matter, since in their judgment the groundwork for a *permanent* classification was not yet sufficiently broad and firm, and they felt much apprehension respecting the trammeling effects of sanctioning a premature classification. Thoughtful geologists who have given the matter careful study will quite generally agree that much is yet to be learned of fundamental facts and principles before a classification can be authoritatively adopted as the mature judgment of the geologists of the world without great risk of hampering the progress of true classificatory ideas. It seems not unlikely, therefore, that an authoritative adoption of a general classification will continue for some time to be regarded as a great end to be ultimately reached, but not wisely attempted until the foundation is better laid.

In the meantime, what can be done to hasten the great achievement?

A true classification of geologic history must represent its *natural* divisions, if there be such natural divisions. In the judgment

[1] Presented to the eighth session of the International Geological Congress at Paris, August 1900.

of some geologists there are no natural divisions that hold good beyond limited provinces. They recognize no general divisions of a sufficiently definite kind to serve the purposes of a concrete classification. In their judgment the succession of geologic events was a continuous progression. They admit that it was differentiated locally and even continentally, but not so universally as to furnish a good basis for classification. They recognize that the existing classifications are natural in some degree as applied to Europe and America, the regions upon which they have been founded, but they anticipate that they will prove quite arbitrary as applied to other continents and to the world as a whole. Entertaining these fundamental views, they hold that classification should be regarded merely as a convenient arbitrary device, and that the existing systems should give way to a more convenient one, much as the old systems of measurement are giving way to the metric system.

On the other hand, there are those who regard the history of the earth as naturally divisible into important stages whose recognition constitutes a leading function of philosophic geology. None of these contend that there was at any time a universal cessation of sedimentation or a complete break in the continuity of life. They freely admit and affirm that there is a fundamental continuity, but at the same time they hold that progress was not uniform, but pulsative or rhythmical. Specifically, speaking for some of these, they think they find periods of stress-accumulation followed by periods of stress-relief, periods of land-expansion followed by periods of sea-transgression, periods of topographic accentuation followed by periods of base-leveling, periods of climatic uniformity followed by periods of climatic diversity, periods of biologic luxuriance followed by periods of biologic impoverishment, in short, a pulsative progress whose successive phases furnish a natural basis for classification.

The existence of these diverse views is an expression of the imperfection of present knowledge. Were exhaustive data at command it could be determined whether the dominant character of the earth's progress was uniformity or periodicity, and hence

whether we should primarily seek a scale of reference and nomenclature with a uniform arbitrary unit, as the meter or the century, or whether we should strive to measure progress by its inherent waves or nodes, or whether we should seek both impartially.

If the rhythmical view be the most laudable, effort should be directed to the more complete and accurate determination of the nature and limits of the periodicities, and to the modification of present classification, so as to bring it into more complete conformity to these. If the uniformity view be the more laudable, effort should be directed to reducing the adopted divisions to quantitative equality by perfecting the geological column and determining available scales of measurement, both stratigraphic and chronologic.

In either case, or in any other case which any individual geologist may prefer to put in the place of these selected ones, it is necessary to push investigation a long way forward before an International Congress can wisely give its sanction to any specific classification.

Our shortest road to the great end sought will therefore be found in promoting those investigations which will soonest give the needed groundwork. Fortunately these investigations are precisely those which best subserve the higher philosophic purposes of the science. Two phases of this great work stand forth prominently: (1) The systematic compilation and elaboration of the great mass of data produced by studies in all parts of the world, which are not now fully available, save to a few favored workers connected with the great libraries, and to these only through much labor duplicated in every individual case. It will be admitted without discussion that the collocation and organization of existing and forthcoming data would greatly stimulate accretions and promote the end sought. (2) *The development of additional criteria of correlation. A preëminently essential step in the progress of classification and interpretation is an increase in the precision and the certainty of correlation of formations in widely separated regions.*

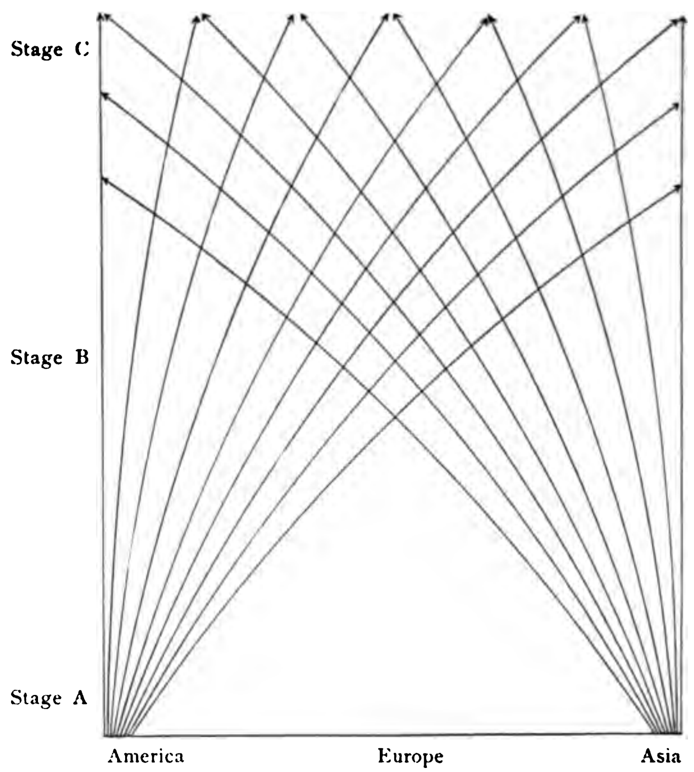
At present the general conviction prevails that there is but a single trustworthy basis of correlation between separated regions, and that even this is subject to some important qualifications, and in many cases is wholly unavailable. I need not mention fossil contents. But while fossils are, and apparently must ever remain, the chief means of correlation, it has been the growing conviction of my recent years that certain important improvements and extensions of the criteria of correlation are possible. These embrace (*a*) an improvement of the paleontologic criteria by correcting them for the uncertainties and errors introduced by migration; and (*b*) the addition of physical criteria to the paleontologic ones in such a way as to eliminate some of the uncertainties of the latter, and to serve in their place when they are not available, as is so often the case.

It is neither appropriate nor possible to set forth these adequately here, but I should fail to duly magnify the importance of the measure herein advocated if I did not at least try to indicate the greatness of the possibilities which we might hope to realize if we had the means at our command.

(*a*) The line of improvement in paleontologic correlation may be best illustrated by a concrete example. Let it be supposed that a provincial fauna arises in a harbor of refuge during a time of sea-withdrawal from the continental shelf[1] on the border of America in a given stage A; that by the subsequent development of an adequate sea-shelf or a connecting series of epicontinental seas, this fauna migrated to the shores of Europe during stage B, and that ultimately it reached the coast of Asia in stage C. By the simple application of the criterion of community of species, stage C of Asia would be correlated with stage A of America, and although the time-interval might not be very great, the error growing out of it might seriously disconcert the correlation of associated physical events, and prevent their correct interpretation. But if during the stage A there developed in a harbor of refuge on the coast of Asia another provincial

[1] "A Systematic Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. VI, No. 6, Sept.-Oct. 1898, pp. 604–608.

fauna, and if this, for like geographic reasons, was permitted to reach Europe in stage B, and America in stage C, a different set of errors of interpretation would be likely to arise from the simple criterion of community of species, for the commingled faunas would appear in America and Asia only in stage C, while they would appear in Europe as early as stage B. So too, in



America and Asia, in stages A and B, only the respective provincial faunas would be found. The situation is illustrated in the accompanying diagram. But if the fact of the provincial origins of the two faunas and their subsequent migration can be established, a much more accurate correlation will be possible. The deposits of stage A in Asia and America will be correctly

assigned to the same period, though they have no species in common, and the other stages will fall into their proper sequence. This may suffice to illustrate one method by which the migration, *and particularly the cross-migration*, of faunas may be brought into service in the correction of the errors of correlation arising from dependence simply on the presence of common fossils. It will furthermore be recognized with acclaim that the tracing out of the origins and migrations of the ancient races of the earth's inhabitants has independent and profound interest, and that it is peculiarly and necessarily an intercontinental work.

But the origin and migration of faunas and floras is peculiarly dependent on physical conditions. I am persuaded that this is most eminently true of the origin of provincial faunas and their evolution into cosmopolitan faunas, as I have endeavored to set forth in recent papers.[1] While it will doubtless always be quite difficult to detect the point of origin and the course of migration of *single species*, there is reasonable ground of hope that the origin of provincial *faunas* may be located, and their migrations and fusions followed until they are lost in cosmopolitan faunas. I have given reasons elsewhere for believing that the general production of provincial marine faunas of the shallow-water type is connected with the withdrawal of the sea from the upper face of the continental platforms, associated with surface warpings, by the first of which the areas of shallow water are restricted, and by the second dissevered from each other.[2] It is therefore believed that much aid in rendering paleontologic interpretations more significant, more certain, and more precise may be derived from the study of the bodily movements of the earth and of the evolution of the geography of the continents in their migratory relations. Certainly and admittedly

[1] "The Ulterior Basis of Time Divisions and the Classification of Geologic History," JOUR. GEOL., Vol. VI, No. 5, July-August 1898, pp. 449–526.

"A Systematic Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. V, No. 6, Sept.-Oct., 1898, pp. 597-608.

"The Influence of Great Epochs of Limestone Formation on the Constitution of the Atmosphere," *Ibid.*, pp. 609–621.

[2] The first two papers above cited.

this is eminently true of land faunas whose migrations are essentially dependent on terrestrial connections, and I believe it is scarcely less true that the migration of the more immobile portion of shallow water sea faunas is dependent on continental shelves and epicontinental seas. If, therefore, there be a periodicity in the great bodily movements of the earth and sea, and a consequent periodicity in the origination of provincial faunas, there will be all the greater field for the application of principles founded on migration and counter-migration to the working out of more precise correlations.

(*b*) There is reason to hope that the sea itself may be made an important aid in intercontinental correlation, for it makes, and always has made, *a simultaneous record on all the continents.* The difficulties lie solely in reading the record.

The ocean volume may not have been accurately constant at all times, but its variations between closely related periods can never have been more than a negligible fraction of the whole volume. Its record is made on the border of a single complex basin, for all the oceans are united and have a common water level. Apparently there has always been essentially a single complex basin, though this cannot be rigorously affirmed. Assuming it, however, any deformation of the basin in any part, which affects its capacity, is recorded on all continents by a new shore line. Setting aside compensatory warpings, this involves a universal advance or retreat of the sea, and a corresponding change in the areas of sedimentation and erosion. It involves, also, a change of land and sea faunas by expanding and contracting their habitats respectively, and by extending or restricting their means of migration. Were it not for the attendant warpings of the land, these sea changes would furnish a simple means of world-wide correlation of the most precise and specific kind. Conjoined with paleontology they would leave little to be desired so far as marine stages are concerned. There remains, however, the problem of eliminating the disturbing effects of concurrent warping. To some large extent it is the warping that changes the capacity of the ocean basins. Warping may even disturb

the local attitude of the land to the sea without affecting the capacity of the ocean basin, for the warping up in one region may be compensated by the warping down in another region. The subject is therefore attended by grave difficulties, but it is not without sufficient ground of hope to justify systematic study. There are at least two general phases of earth-action whose effects promise to rise above those of local warpings to such a degree as to be determinable and to be serviceable in intercontinental correlation. They are the stages of great shrinkage and the stages of relative quiescence. Whatever views may be entertained of the early history of the earth or of its internal constitution, it will probably not be questioned that the oceanic bottoms have, on the whole, shrunk more than the continental platforms. The very existence of the continents in spite of erosion is an expression of this. It will perhaps not be denied that the shrinkage adjustments of the exterior of the earth have been periodic and that the basins have been deepened and the land relatively elevated at the periods of adjustment; at any rate, this may be made a working hypothesis, coördinately with its opposite, until the truth is ascertained.

Between the assumed periods of adjustment, periods of relative quiescence may be recognized as their necessary complement. These were only relatively quiescent, for local and regional warpings were quite certainly in progress at all stages of geological history. In these stages of relative quiescence the volumetric erosion of the land may quite safely be assumed to have exceeded the volumetric elevation, and the material transported to the sea may be assumed to have exceeded any increase of the capacity of the ocean basin due to shrinkage. Without these assumptions it seems to me difficult to explain specifically the history of erosion and sedimentation; but, as this may be doubted, let the assumptions stand merely as working hypotheses. The result of such erosion would be the partial filling of the common ocean basin and the extension of the sea upon the land. Taking Murray's estimate of the present average height of the land, a volumetric reduction and transference of one half

the protruding portion would raise the sea level somewhat more than one hundred meters, an amount sufficient, in the lowered state of the continents, to notably extend the marine area and change the distribution of life.

Here, then, hypothetically are two systematic causes tending to produce universal changes in the relations of sea to land, the one dependent on the accumulation of shrinkage stresses by reason of the effective rigidity of the earth, and the other dependent upon erosion during relatively quiescent stages. Now, if by the compilation of great masses of data the disturbing effects of local warping can be eliminated, a means of intercontinental correlation, independent of the paleontologic, and fundamental to it, may be obtained. By combining the dynamic with the paleontologic the testimony of both may be enhanced and the significance of the latter greatly increased.

The application of the method obviously requires the massing and handling, quantitatively as well as qualitatively, of all possible data from all parts of the world, and can only give results of the highest order of trustworthiness when the mapping of the whole earth approaches completion, but there is reason to believe that initial results of no small value might even now be secured if all existing data could be marshaled.

The constitutional states of the atmosphere furnish a third source of hope of supplementary means of correlation. If the view that the atmosphere originally contained all or the larger portion of the elements which have been taken from it, notably the carbon dioxide, and that its history has been one of continuous depletion, and that, aside from a slow decline in temperature, climatic changes have been due merely to local agencies, be correct, there is little ground of hope for results of much value in correlation. But if, on the other hand, as recently postulated,[1]

[1] A Group of Hypotheses Bearing on Climatic Changes. JOUR. GEOL., Vol. V, No. 7, October-November 1897.

The Influence of Great Epochs of Limestone Formation on the Constitution of the Atmosphere, JOUR. GEOL., Vol. V, No. 6, September-October 1898, pp. 609–621.

An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis, JOUR. GEOL., Vol. VII, Nos. 6, 7, and 8, 1899.

the carbon dioxide of the atmosphere has been mainly supplied concurrently with its consumption, and the amount has varied with the ratios of supply to consumption, and these ratios have been dependent upon the extent of the land and the condition of the sea, and if further the impoverishment of the atmosphere in carbon dioxide is determinable by the unusual prevalence of certain kinds of deposits, as salt, gypsum, red clastics, and glaciated bowlder clays, while its enrichment is indicated by equable temperatures and mild climates in high latitudes, there is ground for hoping that the constitution of the atmosphere may be made to afford a valuable means of correlation applicable when the paleontologic criteria are most liable to fail. Effects due to the constitution of the atmosphere must be universal and strictly simultaneous, though of course not everywhere identical. For example, in India, Australia, and South Africa, an abrupt change in the flora took place at some time near the transition from the Carboniferous to the Permian period. Fontaine and White have found an abrupt, though less radical, change in the flora of eastern America at about the same time, but there are no paleontological means at present known by which these changes can be accurately correlated. The change in India, Australia, and South Africa is closely associated with glacial deposits. Now, if glaciation be a result of a *constitutional* state of the atmosphere, such state should make itself felt *in all parts of the earth simultaneously*, though in different ways and degrees, and the floral change in eastern America could with good reason be strictly correlated with the changes in Asia and the southern hemisphere, and should find verification in similar changes elsewhere. This is merely a hypothetical illustration. The supposed atmospheric mode of correlation should be verifiable by its peculiar effects, for it should simultaneously affect distant floras made up of different constituents, a phenomenon differing in nature from the effects of simple migratory replacement or biologic evolution.

It is obvious, however, that correlation by atmospheric states can only become a trustworthy dependence by the

massing and careful adjudication of data from all parts of the world, for the sanction of the method will largely depend on its success in conforming to and elucidating world-wide phenomena. Both this and the preceding method will require first to be established by trial before they can be independently applied, but this was equally true of the paleontologic criteria at the outset.

The very establishment of these atmospheric and oceanic criteria, or their disproof, would go far to settle the fundamental question whether the earth's history is naturally divisible into periods or not. If there be secular accumulations of stress in the body of the earth, followed by adjustments when rigidity is overcome, and if these adjustments change the respective areas of land and sea, and these in turn result in changes in the constitution of the atmosphere and in the evolution of life, these cycles must be factors in the ultimate basis of a rational classification of geologic time, and must at the same time express some of the most profound and significant features of the earth's history.

The doubt as to whether these things be so or not can only be resolved by studies as broad as the earth. Such studies are not only international and intercontinental, but they are omniterrestrial. The shaping they have been given here is that of an individual student and expresses his limitations, but the breadth and importance of the problems themselves will not be questioned.

Now it is far beyond the functions and the resources of any present official organization to adequately cope with these great problems. There is not even an organization at present that is provided with the men and the means to bring promptly together, arrange, and tabulate for the common benefit of geologists the data that are being gathered by official and private investigations; much less is there any organization that can build these into their organic relations, or draw forth from them their full significance and make this serviceable in further investigation. Nor is there any organization provided with any notable means

for systematically supplementing the work of official and private surveys where such auxiliary work is most needed. A few universities and a few generous individuals provide means for particular expeditions and these have great value and should command our profoundest appreciation, but they are not, and cannot be expected to be, systematically related to classification or to the other general questions under the special patronage of this body.

I beg to urge, therefore, upon the International Congress the inauguration of a systematic movement looking to the determination of the fundamental facts upon which an ultimate classification may be founded.

The practical suggestion I ask leave to offer is an appeal to the generous people of our several nations for the means to establish a permanent institute, or group of coördinate institutes, which shall be devoted to this purpose and to others germane to it. Specifically these purposes may be summarized as follows:

1. The collocation, systematic arrangement, and publication of existing and forthcoming data bearing upon the fundamental facts and principles upon which a final classification must be founded.

2. The gathering of literature, especially that now least accessible, and, so far as practicable, of typical collections bearing on the special objects of the organization.

3. The elaboration of data by combination, computation, and correlation, both independently of all hypotheses and in specific application to the various hypotheses that may be propounded.

4. The encouragement, and so far as practicable, the conduct of field investigations in regions not cultivated by existing organizations, nor reached by private enterprise.

The magnitude and duration of the work would require that the institution be permanent. If the task of the complete correlation of the earth's formations be assumed it is doubtful if the function would ever be entirely fulfilled.

The generosity with which great institutions of learning have been founded and expensive scientific expeditions equipped gives encouragement to the hope that if the noble object were suitably made known, the means for its realization would be forthcoming.

It may seem premature to discuss details of organization and modes of control before the general nature of the proposition is approved, or substantial encouragement be given that the necessary means of carrying it into effect will be available, but the practicability of the proposition is in some measure dependent on the concrete form which it would take. This is a peripatetic body of changing membership, and, so far forth, is not most happily organized to administer an enterprise of this kind. The congress, furthermore, represents many nations and could not be hoped to be entirely at one as to the location and control of a permanent institution of this kind. It is, furthermore, probable that patrons of the proposed organization would be influenced by patriotic sentiments in making contributions to the endowment. It seems best, therefore, to recognize these conditions in the proposition itself, and instead of endeavoring to establish a single international institution under the specific control of this body, to urge the establishment of sections or branches or coöperative members of a composite organization to be located in as many nations or grand divisions of the globe as future developments might render wise; these sections or branches to be immediately administered by such bodies in such nations or grand divisions as were found most suitable and practicable. For example, in America, a section or a coöperative institution might well be established under a board of trustees elected by the Geological Society of America, a permanent organization of definite membership, representative of geological activity on the North American continent. Similar representative societies or fixed geological organizations fitted for the control of other branches or coöperative institutions exist, or if not, should be brought into existence, in all the great nations or grand divisions. Such regional organizations would possess certain advantages in the

collection of data from the fields they would specially represent. The function of the International Congress would embrace the inauguration and coördination of these, the advisory control of their lines of effort, the adoption of their partial results as reached from time to time, and the creation of international sentiment in their support.

T. C. CHAMBERLIN.

UNIVERSITY OF CHICAGO,
July 25, 1900.

THE COMPOSITION OF KULAITE

SEVERAL years ago I published[1] as an inaugural dissertation an account of the volcanoes of Kula, in Lydia, Asia Minor. In this the recent lavas of the region were described, to which rocks the name of "Kulaite" was given, the definition being, "a subgroup of the basalts which is characterized by the presence of hornblende as an essential constituent, which surpasses the augite in quantity and importance." The varieties of leucite-kulaite and nepheline-kulaite were also recognized, the essential character of all being the predominance of hornblende over augite.

Although the analysis made for me by Dr. Röhrig showed, for basalts, abnormally high Na_2O, yet little attention was paid to this feature and, attempts at identifying nepheline in the groundmass having failed, the kulaites were regarded essentially as plagioclase-basalts in which the pyroxene was largely replaced by hornblende.

In his latest book, Rosenbusch[2] recognizes this combination of high alkalis with a basic combination, and refers them to his group of trachydolerites, an intermediate group corresponding to the latities of Ransome,[3] which are effusive equivalents of the monzonites and intermediate between trachytes and andesites or basalts.

Study of other rocks of Asia Minor, which also showed similar latitic features, as well as the growing importance of these intermediate types, also called my attention again to the Kula rocks, and led to a reëxamination of them. This seemed

[1] The Volcanoes of the Kula Basin, in Lydia, New York, 1894.

On the Basalts of Kula, Amer. Jour. Sci., Vol. XLVII, p. 114, 1894.

[2] ROSENBUSCH: Elemente der Gesteinslehre, p. 342, 1898.

It is uncertain whether Rosenbusch understood these rocks to be without any feldspar at all, or only without feldspar phenocrysts.

[3] RANSOME: Amer. Jour. Sci., Vol. V, p. 373, 1898.

especially needful chemically, since, as was pointed out to me by Professor Iddings, judging from the description published in 1894, there seemed to be no mineral present which would account for the high alkalis. In addition, for such basic rocks, Al_2O_3 seemed to be very high and MgO very low, and it was feared that Dr. Röhrig had made the common error of precipitating some MgO along with the Al_2O_3. I am happy to be able to say that two analyses, made by me with especial care in regard to this point, show conclusively that in this respect Röhrig's analyses are quite correct.

As the rocks have been already described, it is not necessary to go into any lengthy account of their mineralogical features, and only the two analyzed will be mentioned.

The rock from a depth of 35 meters in a well digging in Kula is light gray, fine grained and slightly vesicular, with small phenocrysts of olivine and pyroxene visible. In thin section phenocrysts of pale gray pyroxene (diopside), olivine and of hornblende, which last in every case have been completely altered to a mixture of diopside and magnetite, are seen lying in a holocrystalline groundmass. This is composed of bytownite laths, small crystals and anhedra of diopside, magnetite grains and small apatites, with an ill defined, colorless mesostasis of low refractive index and small birefringence, which was previously referred to accessory orthoclase.

The tests made in Leipzig failed to reveal the presence of nepheline, but these have been lately repeated with care, and they prove beyond question that part of this interstitial, anistropic substance gelatinizes with acid and stains with fuchsine, while part of it remains unaffected. It is therefore established that nepheline is present in this rock, a conclusion in accordance with the results of analysis, as will be seen later.

A second specimen to be described is of a "leucite-kulaite," from the northeast flow of Kula Devit,[1] near the Gediz-chai,

[1] This was spelled "devlit" in the former papers, following earlier authorities (Hamilton, Tschihatcheff) and as the word was apparently understood by the natives. It is really دويت "devit" an ink-stand, and not دولت "devlit" state or government. Cf. Inaug. Diss., p. 12.

Megascopically, this is similar to the other, but is darker gray and somewhat finer grained.

In thin section it shows fewer phenocrysts of diopside and olivine than the other, but more abundant, well-formed, hornblendes, which have all been altered, in some cases entirely, in others only partially, leaving some unchanged hornblende substance in the center. This alternation has not been as thorough as in the preceding, and, while here and there alteration to the usual diopside-magnetite aggregate is seen, in most cases the spaces formerly occupied by hornblende show a mass of the brown, pleochroic orthorhombic rods, which I have identified with hypersthene.

The groundmass is similar to the other, but flow structure is well marked. There are similar plagioclase laths (here andesine), also olivine and diopside crystals, generally stouter and better crystallized, and smaller grains of magnetite but scarcely any apatite. The most important difference is the presence in abundance of small round areas of a clear, colorless mineral, of low refractive index, and generally isotropic, containing inclusions of diopside needles and magnetite grains, arranged either centrally or zonally. While these round spots are mostly too small to show very marked abnormal double refraction, yet they occasionally do so, and there seems to be no doubt that they are to be referred to leucite. The mesostasis here is colorless and almost isotropic and glass-like, but it stains by treatment with HCl and fuchsine.

In the table are given the two analyses recently made by myself, as well as the corresponding ones of Röhrig. A few other analyses of similar rocks are inserted for comparison, and will be referred to subsequently.

It will be seen that Röhrig's analysis of the normal kulaite (II) agrees very well with mine (I) in all respects except in Fe_2O_3 and K_2O, which are respectively about 2 per cent. higher and lower. On the other hand, his of the leucite-kulaite (IV) resembles mine (III) only in MgO, CaO, and Al_2O_3, the TiO_2 present being weighed by him with the Al_2O_3. The other constituents differ rather widely.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
SiO_2	48.35	48.24	49.90	47.74	42.68	41.01	44.77	47.83	48.24	46.48	49.69
Al_2O_3	19.94	20.64	19.89	20.95	9.42	11.58	17.82	16.09	17.43	16.16	18.06
Fe_2O_3	2.48	4.63	2.55	3.29	11.55	12.54	5.05	4.32	7.22	6.17	2.64
FeO	5.25	5.55	4.78	6.32	7.23	7.60	6.95	3.62	1.17	6.09	6.19
MgO	5.15	5.02	5.05	5.16	10.09	8.67	8.22	5.53	3.99	4.02	5.73
CaO	7.98	7.94	7.21	7.56	13.15	12.20	10.36	10.68	6.09	7.35	8.24
Na_2O	5.47	5.08	5.60	7.12	2.71	2.57	2.13	4.46	4.28	5.85	2.99
K_2O	3.99	1.88	3.74	1.21	1.16	1.45	0.92	4.05	4.62	3.08	3.90
H_2O 110°+	0.22	0.02	0.19	0.04	1.06	1.87	2.64	0.24	2.78	4.27	0.91
H_2O 110°−	0.16		0.13					0.05			
CO_2	....	....	....	....	....	....	....	....	....	0.45	....
TiO_2	0.12	....	0.93	....	0.51	0.48	0.53	2.27	2.89	0.99	0.85
P_2O_5	0.84	0.97	trace	0.13	1.29	0.75	0.72	0.47	1.33	....	0.81
Cl	....	....	....	....	....	....	....	....	....	....	0.13
MnO	trace	....	trace	....	....	....	trace	0.38	trace	....	0.13
	99.95	99.97	99.97	99.52	100.85	100.72	100.11	99.56	100.47	100.91	100.27

I. Kulaite. Well digging. Kula. H. S. Washington anal.
II. Kulaite. Well digging. Kula. A. Röhrig anal. Am. Jour. Sci., Vol. XLVII, p. 122, 1894.
III. Leucite-kulaite. Near Gediz-chai, Kula. Washington anal.
IV. Leucite-kulaite. Near Gedis-chai, Kula. A. Röhrig anal. Loc. cit.
V. Hornblende-basalt. Todtenkopfchen, Rhone. Sommerlad anal. Neu. Jahr Beil, Band II, p. 155, 1883.
VI. Hornblende-basalt. Sparbrod, Rhone. Sommerlad anal. Loc. cit.
VII. Hornblende-basalt. Kosk Creek, California. Eakins anal. Diller. Amer. Geol., Vol. XIX, p. 255, 1897.
VIII. Leucite-tephrite. Falkenberg, near Tetschen, Bohemia. R. Pfohl anal. Hibsch. Min. Pet. Mitth. Vol. XIV, p. 105, 1894.
IX. Leucite-nepheline-tephrite. Niedermendig, Laacher See. R. Mitcherlich anal. Zeit. deutsch. geol. Ges., Vol. XV, p. 374, 1863.
X. Monchiquite. Cabo Frio, Brazil. M. Hunter anal. Hunter and Rosenbusch. Min. Pet. Mitth., Vol. XI, p. 454, 1890.
XI. "Basalt." Table Mountain, Denver, Colorado. Eakins anal. Cross. Mon., XXVII U. S. Geol. Surv., p. 308, 1896.

As the original specimens were small, these differences cannot be ascribed to differences of composition in different parts of the mass, but are more probably due to the different analytical methods used. This applies especially to the alkalis, in the determination of which the usual German method of treatment of the rock with HF and H_2SO_4, and subsequent separation of Al, Fe, Mg, and Ca, instead of the much more expeditious and accurate method of J. Lawrence Smith, tends to erroneous and discrepant results largely through contamination with alkalis derived from the glass vessels and reagents employed.

Having thus obtained an insight into the chemical and mineralogical composition of these rocks, it will be well to determine their place in the present scheme of classification.

In the first place, the very close correspondence of both my analyses, except in the minor constituents TiO_2 and P_2O_5, show that, in any scheme based on this character alone, they are to be classed together. Indeed, this is true of all the rocks of the Kula region examined by me, as shown by the analyses of Röhrig given in the original paper.

From a purely chemical standpoint it is abundantly evident that they are not to be referred to the basalts as this name is at present understood, since the alkalis are far too high for this group of rocks. The alumina is also too high, at least in comparison with the basalt analyses in which this constituent has been determined with proper care. Nor are they to be put with the subgroup of hornblende-basalts, as is shown by comparison with some typical analyses of these given in V, VI, and VII. The Kula rocks differ from these in having higher SiO_2, Al_2O_3 and alkalis, and lower iron oxides, MgO and CaO. In other words, they are more properly leucocratic, while the hornblende-basalts are melanocratic. At the same time the hornblende-basalt from Kosk Creek (VII), described by Diller, occupies a rather intermediate position between the Kula rocks and the typical hornblende-basalts of the Rhone and other regions.

The closest analogues of the Kula rocks are to be found among the nepheline-tephrites and nepheline-basanites. It is

true that many of these are markedly lower in SiO_2, Al_2O_3 and Na_2O, but at the same time analyses of these are to be found which closely resemble mine of the Kula rocks, as those of the nepheline-tephrite from the Falkenberg, near Tetschen, Bohemia, described by Hibsch (VIII), and the leucite-nepheline-tephrite of Niedermendig (IX).

They also resemble closely the monchiquites, as shown by a typical analysis of one of these (X), the main difference being in the higher content of H_2O in the monchiquites, consequent on their containing analcite in place of nepheline.[1]

Rocks which chemically closely resemble these are certain "basalts" from Colorado, described by Cross, an analysis of one of which is given in XI. These carry considerable orthoclase, but no nepheline, and with biotite instead of hornblende.

Turning to the mineralogical composition, it must be noted that most of the Kula rocks present a peculiarity which adds somewhat to the difficulty of classification. They have been spoken of as containing hornblende as an essential constituent. This is strictly true only of the more glassy varieties, in which basaltic hornblende is fresh and unaltered. In the others — including those analyzed — this mineral has been partially or entirely altered to hypersthene, diopside and magnetite, so that, speaking with strict accuracy as to their present composition the majority of them cannot be said to contain any hornblende at all.

This naturally raises the difficult question, whether the original hornblende should be recognized as a component. Of its initial presence, and the derivation of the hypersthenic and diopside-magnetite "mixed crystals" or pseudomorphs from it there can be absolutely no doubt, from the evidence of the shape of the pseudomorphs, the transitions to unaltered hornblende, and other facts observed here and elsewhere.

The case is strictly comparable with the occurrence of so-called "pseudo-leucites," mixtures of orthoclase and nepheline or muscovite, pseudomorphous after original leucite. As

[1] Cf. L. V. Pirsson: Jour. Geol., Vol. IV, p. 679, 1896.

rocks containing these are called "leucite-syenite," "leucite-eleolite-syenite" and "leucite-phonolite" by Rosenbusch and Zirkel, it would seem to be justifiable, at least for the present, to speak of the Kula rocks as hornblende-bearing.

The analyses I and III calculate out very sharply as shown in the table below, with results worth commenting on. In the

	I a	III a[1]
Anorthite	17.9	17.9
Albite	8.4	23.6
Orthoclase	23.4	..
Leucite	..	17.4
Nepheline	20.4	12.8
Diopside	12.8	13.8
Olivine	10.7	9.5
Magnetite	3.7	3.7
Apatite	1.8	..
Water, etc.	0.8	1.3
	99.9	100.0

first place this calculation confirms the observation that nepheline is present, as there is too much Na_2O or too little SiO_2 to satisfy each other on any other basis.

It is also of interest to note that, although these rocks are so basic in composition, and so basaltic in general habit and appearance, yet the feldspars and feldspathoids constitute over 70 per cent. of the mass, and that they consequently are leucocratic, to use the distinction into two groups recently given by Brögger.[2] So little is known of the rocks of Asia Minor that as yet no melanocratic complements of these are positively known, though it is to be expected that they will be discovered some time in this petrographic province.

It will be noticed that in I the plagioclase is a bytownite of the composition Ab An_4, while in II it is an andesine, approximately Ab_3 An_2. It is certainly remarkable that in the one

[1] Inasmuch as diopside, hornblende, hypersthene and olivine are present together in III, it is impossible to calculate the exact relative amounts of each, and the analysis has, therefore, been calculated on the assumption that only diopside and olivine are present. The error involved will not be large, as the hornblende tends to alter to a mixture of diopside and magnetite.

[2] BRÖGGER: Erupt. gest. d. Kristianiageb, III, p. 263, 1898.

rock orthoclase is associated with the lower SiO_2, as well as with a bytownite, while in the other leucite occurs with higher SiO_2 and lower K_2O, and with the plagioclase an andesine. In the latter also the albite molecule is higher and nepheline correspondingly lower, while the other constituents (except apatite) remain the same.

This is peculiar, but there seems to be no doubt of the facts, and the difference is possibly to be connected with differences in the conditions of solidification. The specimen of I came from a depth of thirty-five meters in a lava flow, possibly of Kula Devit, but more probably of an earlier volcano, while the leucite-kulaite was from the surface of a late flow of Kula Devit.

There would thus have been certain, even if slight, differences in pressure and rate of cooling, which might account for the difference in mineralogical composition. It has already been pointed out elsewhere[1] that these intermediate latitic magmas seem to be in a nicely balanced state of chemical equilibrium which only need very slight differences in conditions of solidification to result in quite diverse mineralogical aggregates. The facts here are also in accordance with the general observation that leucite is essentially a mineral of the effusive rocks, while orthoclase occurs in either intrusive or effusive masses, this tendency toward the formation of leucite in flows in contradistinction to the formation of orthoclase in domal eruptions being especially well seen along the main line of Italian volcanoes.[2]

We have already seen that the analyses correspond most nearly with those of the tephrites. Accepting, however, the general definition of a tephrite as an effusive rock composed essentially of plagioclase and nepheline or leucite, with pyroxene or other ferromagnesian components, it is very clear that the rock represented by analysis I, which contains 23 per cent. of orthoclase, cannot properly be put in this group. Indeed,

[1] H. S. WASHINGTON: JOUR. GEOL, Vol. V, p. 376, 1897.
F. L. RANSOME: Amer. Jour. Sci., Vol. V, p. 370, 1898.

[2] Cf. JOUR. GEOL., Vol. V, p. 376, 1897.

the calculated mineral composition, yielding 23.4 per cent. of orthoclase and 26.3 of plagioclase, is fully corroborative of the position to which Rosenbusch assigns this rock, among the latites or trachydolerites.

It would seem, then, advisable, as well as justifiable, to reserve the name "kulaite" to denote a basic rock of the series of latites (Rosenbusch's trachydolerites), in which orthoclase and lime-soda feldspar are present in about equal amounts, together making up half the rock, with nepheline to the extent of from 12.5 to 25 per cent. The ferromagnesian constituent is typically hornblende or pseudo-hornblende, and diopside and olivine are also present. These rocks, though low in silica, are essentially leucocratic in character.

The case of the "leucite-kulaites" is rather different. On the basis of chemical composition and genetic association they would naturally be classed with the kulaites, as varieties of these in which leucite replaces orthoclase. At the same time, composed as they are of plagioclase, nepheline and leucite, with ferromagnesian minerals, they are perfectly covered by the tephrites, and in the present schemes must be called leucite-nepheline tephrite.

I have gone at some length into the question of the position and names of these rocks, not because the matter is of any great importance in itself, but because they serve very well to exemplify the difficulties and complexities of our present methods of classification. It is the old story of magmas of identical chemical compositions solidifying as different mineral aggregates. With the rapid increase in our knowledge of rocks, and especially through more numerous analyses and their more careful execution, examples of this are becoming of quite frequent occurrence in petrographical literature. Most cases, as those of venanzite and madupite, the minette or selagite of Monte Catini and wyomingite, and many more, are of rocks from widely distant parts of the globe.

Here, however, there are found at one small center recent flows which must be referred to the distinct groups of basic

latites, leucite-tephrites and, to include the tachylitic varieties described in the original papers, hornblende-limburgites. These rocks which, according to the principles of classification at present in vogue, we must place in such diverse and distant parts of our scheme, are all products of one center of eruption, parts of the same undifferentiated magma, identical in chemical, and in many points of mineralogical, composition. A rational or natural scheme of classification should express their evident close relationship, but on account of somewhat diverse mineralogical composition, due to such extraneous and accidental causes as conditions of cooling and the like, their mutual affinities are to a large extent masked by the diverse names which must be given them.

We are brought face to face with the question, whether we should hold to the present system, based on structure and (largely qualitative) mineral composition; or whether we should strive to base our classification primarily on the most fundamental character of igneous rocks—their chemical composition, the quantitative mineral composition being a function and an exponent of this.

The choice of the latter would certainly seem to be justified on sound theoretical grounds, and has been advocated by Pirsson,[1] Iddings,[2] Brögger,[3] Loewinson-Lessing,[4] and others. It is, of course, also well known that Brögger holds that genetic relationships should find expression in classification; in other words, that the system of classification should be not a Linnean but a natural one. But discussion of this and kindred topics would carry us far beyond the limits of this paper.

That any change will present difficulties of a practical as well as of a theoretical nature is obvious. The aid of chemical analysis, as well as of the microscope, must be invoked much more often than in the past, though with increasing knowledge

[1] PIRSSON, Amer. Jour. Sci., Vol. L, p. 478, 1895.

[2] IDDINGS, JOUR. GEOL., Vol. VI, p. 103, 1898.

[3] BRÖGGER, Amer. Jour. Sci., Vol. IX, p. 458, 1900.

[4] LOEWINSON-LESSING, Compt. Rend., VII, Cong. Geol. Int., 1897, pp. 193–464.

this would be less vital in many cases than may be thought by some. Cases of uncertainty as to the position and relationships of a particular rock will occur, but presumably less frequently than under the present system. These and other difficulties will have to be met and overcome. But, as Iddings, Brögger, and others have urged, the time is at hand for a revision and change of our whole system of classification and subsequently of nomenclature, and it is well to remember the general truth of the saying, "*C'est le premier pas qui coûte.*"

HENRY S. WASHINGTON.

SUCCESSION AND RELATION OF LAVAS IN THE GREAT BASIN REGION[1]

RICHTHOFEN'S STUDIES

THE Great Basin was early recognized as showing a variety of Tertiary lavas which are identical over large areas, and erupted in somewhat the same succession. The first deductive studies from these facts were made by the Baron von Richthofen,[2] and were published in 1867. Partly as a result of observations in the rocks of the Great Basin and of California, and partly from studies in the volcanic regions of Europe, Richthofen arrived at what he considered to be the natural law for the sequence of massive eruptions, applicable to all centers of volcanic activity. According to him the order of succession was :

1. Propylite.
2. Andesite.
3. Trachyte.
4. Rhyolite.
5. Basalt.

This law of succession was accepted without much question for a long time by many European and American geologists.

THEORIES OF THE ORIGIN OF IGNEOUS ROCK DIFFERENCES PREVIOUS TO RICHTHOFEN[3]

By way of summarizing briefly the difference between Richthofen's theories and those of his predecessors, it may be remarked that Bunsen, who was one of the first to speculate concerning rock differences, after visiting Iceland and studying the volcanic phenomena, formed the hypothesis of two distinct magmas or bodies of lavas, one acid, and the other basic; the normal "trachytic" and the normal "pyroxenic" magmas,

[1] Published by permission of the Director of the United States Geological Survey.

[2] "Natural System of Volcanic Rocks," Mem. California Acad. Sci., Vol. I, p. 36.

[3] See Monograph XX, U. S. Geol. Surv., p. 273.

as he called them. He regarded all lavas between these extreme types as mixtures of the two in varying proportions. It will be noted that Bunsen's explanation[1] was essentially a theory of mixing rather than of differentiation.

Durocher[2] accepted Bunsen's idea of the existence of an acid and a basic magma, and admitted the possibility of a mingling of the two in certain cases to produce intermediate types, but did not follow this idea to the extent of Bunsen. Durocher proposed the hypothesis, which was not substantiated by much study of volcanic action in the field, that certain lavas may be produced by segregation, or differentiation, *i. e.*, by the breaking up of a magma into several different parts, as a result of chemical activity. Durocher's ideas of the origin of igneous rocks, therefore, include the idea of segregation, or differentiation, together with that of mixing.

Roth[3] later also held that a magma may segregate during crystallization into lavas of different mineralogical composition, although his ideas of the processes of differentiation were not specifically identical with those of Durocher, who had considered these processes analogous with those by which metals are segregated in metallurgical operations.

Von Waltershausen,[4] after studying the lavas of Sicily and Iceland, came to the conclusion that lavas were derived from a zone of molten material between the earth's crust and its solid interior, and that the material arranged itself according to the laws of gravitation, so that the most siliceous lava, which is also the lightest, was nearest the surface; the most basic at the bottom, and the intermediate lavas in the zones between. His own observations in the field seemed to point out that the lavas were

[1] Ueber die Processe der vulkanischen Gesteinsbildung Islands, Poggendorf's Annalen, 1851, Band 83, pp. 197–272.

[2] Essai de Pétrologie comparée, Ann. d. Mines, Paris, 5th series, 1857, Tome XI, pp. 217–259.

[3] Tabellarische Uebersicht der Geistens-Analysen, mit kritischen Erläuterungen, Berlin, 1861.

[4] Ueber die vulkanischen Gesteine in Sicilien und Island und ihre submarine Umbildung, Göttingen, 1853.

thrown out according to their supposed superposition, the order being, therefore, regularly from acid to basic lavas.

KING'S WORK AND ITS LATER MODIFICATIONS

The first careful work on the lavas of the Great Basin was done during the 40th Parallel Survey, the field-work of which was done chiefly by Messrs. Hague and Emmons, while the petrographic work was by Professor Zirkel, and the general results and deductions were made by the director, Mr. Clarence King.[1] Mr. King accepted in general the law of succession of volcanic rocks, as laid down by Richthofen, but subdivided the lavas of each member of the succession, and united the fourth and fifth members — the rhyolite and basalt[2] — under a general term, "Neolite." The natural order, as interpreted by King, was as follows:

Order	Subdivision
1. Propylite	*a.* Hornblende propylite. *b.* Quartz propylite. *c.* Augite propylite.
2. Andesite	*a.* Hornblende andesite. *b.* Quartz andesite (Dacite). *c.* Augite trachyte.
3. Trachyte	*a.* Hornblende-plagioclase trachyte. *b.* Sanidine trachyte (quartziferous). *c.* Augite trachyte.
4. Neolite	*a.* Rhyolite. *b.* Basalt.

As regards the laws maintained by Richthofen and King for the Great Basin, it is necessary to observe first of all that the first member — propylite — was proved by Mr. George F. Becker[3] to be simply a decomposed phase of the andesite in the Washoe district, instead of a separate rock, as supposed by Richthofen

[1] Geological Explorations of the 40th Parallel, Vol. I, p. 545 et seq.

[2] This colligation of rhyolite and basalt was made by King on the basis of their close association in the field. His explanations of this fact, however, were essentially different from later ones, now generally accepted, and first advanced by Mr. Hague, Mon. XX, U. S. Geol. Surv.

[3] Geology of the Comstock Lode, Washoe District, Mon. III, U. S. Geol. Surv., p. 88.

This conclusion was corroborated by subsequent investigators in different parts of the world, so that the term has passed out of use. It has also been proved by Mr. Becker's studies, and later by those of Messrs. Hague and Iddings,[1] that the trachytes of Richthofen and of the 40th Parallel Survey, as determined by Zirkel, are mainly andesites — in part hornblende-mica andesite, and in part hypersthene-augite andesite (the latter rock corresponding more nearly to the augite-trachyte of Zirkel), while a smaller proportion are dacites, and some are probably rhyolites. It has been determined by these investigators that trachyte is conspicuously absent in the province of the Great Basin. The reason for Zirkel's false classification was the lack of means at that time to determine the feldspars, so that the plagioclases were determined as sanidine, since they showed little or no striation.

SUCCESSION OF LAVAS PREVIOUSLY DESCRIBED IN THE GREAT BASIN AND VICINITY

Eureka district.— In the course of a careful study of the volcanic rocks of the Eureka district in Nevada, Mr. Hague[2] arrived at the following succession of lavas at this center of volcanic activity:

1. Hornblende andesite.
2. Hornblende-mica andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene andesite.
6. Basalt.

Washoe district.— In the Comstock or Washoe district, at the southern end of the Virginia Range, Mr. Becker[3] found the following succession of igneous rocks:

1. Granite.
2. Diorite.
3. Quartz-porphyry.

[1] "Volcanic Rocks of the Great Basin," Amer. Jour. Sci., June 1884, p. 453. Geology of the Eureka District, Mont. XX, U. S. Geol. Surv., p. 230 et seq.

[2] Mon. XX, U. S. Geol. Surv., p. 290. [3] Mon. III, U. S. Geol. Surv., p. 380.

4. Earlier diabase.
5. Later diabase.
6. Earlier hornblende andesite.
7. Augite andesite.
8. Later hornblende andesite.
9. Basalt

Messrs. Hague and Iddings,[1] after a careful microscopic study of the collections made by Mr. Becker in the Comstock region, arrived at somewhat different conclusions, although agreeing with Mr. Becker as to the identity of propylite with andesite. They concluded that the granular diorite and diabase, and the augite andesite, were variations of the same body, the granular rocks representing textural differences brought on by slowly cooling in the deeper parts of the extruded mass, while the finer-grained porphyritic rocks represented the periphery of the same. To substantiate their conclusion they show the existence of all possible gradations between the extreme types They also conclude that the porphyritic diorite is identical with the hornblende andesite, and the mica diorite with the later hornblende andesite, the difference in each case being due to variations of texture. The quartz-porphyry of Mr. Becker they regard as partly dacite, and partly rhyolite; while the later diabase, or "black dike," they regard as identical with the effusive basalt. They find, also, that the pyroxene and hornblende andesites are difficult to separate, but that these are cut through by hornblende andesites, dacites, rhyolites, and basalts. The succession of lavas in this district is, according to Mr. Hague:

1. Pyroxene-hornblende andesite (inner portions pyroxene-hornblende diorite porphyry, and pyroxene-hornblende diorite).
   Period of volcanic rest and denudation.
2. Hornblende-mica andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene andesite.[2]
6. Basalt.

[1] "On the Development of Crystallization in the Igneous Rocks of Washoe," Bull. 17, U. S. Geol. Surv.

[2] See Mon. XX, U. S. Geol. Surv., p. 281. Compare the succession in the adjacent Pine Nut Range, p. 628.

The hornblende andesite of Eureka is correlated with the hornblende-mica andesite of Washoe, while the pyroxene-hornblende andesite of Washoe is supposed to belong to an earlier period, not represented at Eureka; otherwise the succession of lavas at the two centers of eruption is considered to be similar and the different extrusions in general contemporaneous.

Sierra Nevada.— Mr. H. W. Turner[1] published in 1895 a résumé of the age and succession of igneous rocks in the Sierra Nevada. According to him the succession of the Tertiary volcanics in this region is as follows:

1. Acid - - - - -	Rhyolite—massive and fragmental.
2. Basic - - - -	Older basalt—always (?) massive.
3. Intermediate - -	Hornblende-pyroxene andesite—chiefly tuff and breccia.
4. Intermediate to acid -	Fine-grained pyroxene andesites—massive
5. Basic - - - - -	Doleritic basalts—massive.
6. Basic - - - -	Other basalts—massive.

In 1898 Mr. F. L. Ransome[2] published a critical study of a portion of the western slope of the Sierra Nevada, in the Sonora and Big Trees region—a locality, it may be noted, much nearer to the Washoe district than the Washoe is to Eureka. Mr. Ransome succeeded in classifying more accurately than had hitherto been done some of the intermediate lavas, determining rocks that had previously been classified variously as basalts, trachytes and andesites as belonging to the monzonitic family, intermediate between the granitic and dioritic families. For the volcanic variety of monzonite he proposed the term "latite." The succession of the Tertiary lavas in the region studied by Mr. Ransome is as follows:

1. Biotite rhyolite.
   Rhyolite tuffs.
2. Olivine-basalt.
3. Hornblende-pyroxene andesite brecca.

[1] JOUR. GEOL., Vol. III, No. 4, May–June 1895.

[2] Bull. 89, U. S. Geol. Surv. Also Amer. Jour. Sci., May 1898, 4th series, Vol. V, p. 355.

4. Latite { Augite-biotite hornblende latite. / Biotite-augite latite. }
5. Hornblende-pyroxene andesite breccia.
6. Olivine-basalt.

Tintic district.— Passing from the Sierra Nevada and the western border of the Great Basin (from the Sonora region and the Washoe district) eastward past Eureka, we will next cite the record of Tertiary vulcanism in the Tintic Range, which lies south of Salt Lake and southwest of Utah Lake, and is approximately the same distance from Eureka as Eureka is from Washoe. This region has been studied by Messrs. Tower and Smith.[1] The succession of lavas is as follows:

1. Biotite rhyolite.
2. Pyroxene-hornblende-biotite andesite — tuffs and breccias.
3. Pyroxene-hornblende andesite (latite).
4. Olivine-basalt.

The rhyolitic flows of the first member of the succession given above are known to be continuous and contemporaneous with dikes of rhyolite which, on account of their somewhat different habit, were given the name of *quartz-porphyry* in the text. This intrusive rhyolite appears to be susceptible of correlation with the rhyolite or "quartz-porphyry," described by the writer,[2] from the northern end of the Oquirrh Range, which lies south of the Tintic district (Eagle Hill porphyry). The rhyolite in the Tintic district is known to be later than Upper Eocene.

The pyroxene-hornblende andesites (or latites) described by Messrs. Tower and Smith are regarded by them as belonging to the same general body as certain large masses of granular monzonite with which they are connected by transitional phases; the monzonite representing portions of the magma which have consolidated as intrusive masses under conditions favoring better crystallization than those under which the extrusive sheets of pyroxene andesite (or latite) have consolidated. These

[1] "Geology and Mining Industry of the Tintic District, Utah," Nineteenth Annual Rept. U. S. Geol. Surv., Part III, Economic Geol., p. 632.

[2] J. E. SPURR, "Economic Geology of the Mercur Mining District," Sixteenth Ann. Rept., Part II, p. 377.

transitions from typical fine-grained extrusives to porphyritic and to coarse granular intrusive rocks are highly interesting in themselves and by comparison with the similar phenomena which Messrs. Hague and Iddings[1] have found in the andesite and basalts of the Washoe district. The present writer has also found similar transitions, to be described elsewhere.

SUCCESSION OF LAVAS AT OTHER POINTS IN THE GREAT BASINS

During the past season's field work the writer has observed the succession of lavas at many different points in the Great Basin. From the nature of the work the time for study was in each case very restricted, so that the records given below are sometimes very likely incomplete.

Pine Nut Range.—The Pine Nut Range is interesting on account of lying immediately south of the Virginia Range and the Washoe district, and because the lavas of this district are easily recognizable in it. The range was crossed at two points, one east from Dayton and one east from Genoa. The succession of lavas appears to be as follows:

1. Rhyolite (intimately connected and probably contemporaneous with granite of similar constitution).
   Rhyolite sands and conglomerates (formed during long period of erosion).
2. Hornblende-pyroxene-biotite andesite (in portions sufficiently removed from the surface the typical glassy or microcrystalline groundmass of the lava becomes coarser, leading to the formation of diorite porphyry and monzonite porphyry).
3. Hornblende-mica andesite.
   Period of denudation.
4. Rhyolite (Shoshone Lake period?).
5. Hornblende-pyroxene andesite, tuffs, and breccias (Shoshone Lake period).
6. Rhyolite.
7. Basalt (Pleistocene).

Of these extrusives the first appears to have been greatest in amount and the latter ones in general progressively less and less, in the order of their arrival.

[1] Bull. 17, U. S. Geol. Surv.

Sweetwater Range.—The Sweetwater Range may next be considered, since it lies south of the Pine Nut Range and shows very nearly the same rocks. It is separated from the Pine Nut Range only by the Walker River Valley, while at its southern end it connects with the Sierras, of which it may thus be considered a spur.

The observed succession of lavas in this range is as follows:

1. Rhyolite (closely connected and perhaps contemporaneous with granites of similar composition).
2. Hornblende-pyroxene andesite.
   Epoch of erosion and subsequent formation of Shoshone Lake.
3. Hornblende-pyroxene andesite, tuffs and breccias.
4. Hornblende-biotite latite.
5. Basalt.

Gabb's Valley Range.—In the lavas of Gabb's Valley and the Gabb's Valley Range, which lies just east of Walker Lake, the following succession was made out:

1. Biotite andesite.
2. Biotite rhyolite.
3. Hypersthene-hornblende aleutite.[1]
4. Augite basalt.

A granular rock, which had every appearance of being effusive, was also found in Gabb's Valley, and on examination proved to be a hornblende-biotite quartz-monzonite. This, however, is not included in the list, since its exact position is uncertain. It is very likely earlier than all the others and is perhaps contemporaneous with the biotite-hornblende quartz-monzonite, which forms the oldest rock in the Walker River Range, being more ancient than the granite.

Silver Peak Mountains.—Mr. H. W. Turner, who has studied the volcanic record in the Silver Peak district, has kindly supplied the writer with the preliminary statement that in general the succession of lavas here is as follows:

1. Rhyolite.
2. Andesite.
3. Basalt.

[1] See American Geologist, April 1900, p. 230.

Ralston Desert.— According to observations made by the writer, the succession of lavas in the Ralston Desert is as follows:

1. Rhyolite and tordrillite[1] (earlier).
2. Rhyolites, often glassy (late Pliocene).
3. Olivine-basalt (Pleistocene).

Practically the same succession is seen in the Kawich Range and in the Reveille Range.

Lake Mono Basin.[2]— In the basin of Lake Mono, according to Professor Russell, we have extensive Pleistocene volcanic activity, the lavas being basalt, hypersthene andesite verging on basalt, and rhyolite. Older than these is a hornblende andesite. The succession in this basin is, then:

1. Hornblende andesite.
2. Basalt, hypersthene andesite verging on basalt, rhyolite.

The relative age of the lavas under 2 was not determined, but they are all regarded as Pleistocene.

Toyabe Range.— In the southern end of the Toyabe Range the known succession of Tertiary lavas is as follows:

1. Biotite rhyolite (closely associated and perhaps contemporaneous with intrusive biotite granite).
2. Augite basalt (Pleistocene).

Schell Creek Range.— In the Schell Creek Range, near Schellbourne, we have the following succession of lavas:

1. Biotite rhyolite (flows often glassy).
2. Pyroxene aleutite (probably late Pliocene).

Egan Range.— In the Egan Range the following lavas were found:

1. Dacite-andesite.
2. Basalt.

Meadow Valley Canyon.— In the Meadow Valley Canyon (southward from Pioche) we have one of the best exposures of Tertiary lavas and their associated sediments which has yet been

[1] See Classification of Igneous Rocks according to Composition, J. E. Spurr, Am. Geol., April 1900, p. 230.

[2] Quaternary History of Mono Valley, California; Eighth Ann. Rept. U. S. Geol. Surv., Part I, p. 374, 379, etc.

found in Nevada. The completeness of the section enables one to see how complicated the history of Tertiary vulcanism and sedimentation is, but the following is the general succession:

1. Biotite rhyolite.
   Rhyolite tuffs and sands.
2. Pyroxene andesite, tuffs and breccias.
   Biotite-hornblende quartz-latite (basic).
   Biotite-hornblende dacite.
   Biotite-hornblende rhyolite, and tordrillite (heavy flows).
   Thin-bedded rhyolite (Pliocene).
3. Pyroxene olivine-basalt.
   Rhyolite-tordrillite. (Pleistocene.)

Funeral Range.—The volcanic activity of the Funeral Range has not been very well observed, but the following is part at least of the succession:

1. Biotite andesite (Eocene or Miocene).
2. Olivine-basalt.

Panamint Range.—In the Panamint Range the following succession of lavas has been observed:

1. Feldspathic lavas of medium acidity; species undetermined.
   Rhyolite.
2. Andesite (late Eocene or Miocene).
3. Pyroxene aleutites and basalts, often olivine-bearing (late Pliocene or Pleistocene).

Randsburg region.—In the mountains in the vicinity of the mining camp of Randsburg, in southern California, the writer observed the following succession:

1. Biotite rhyolite (early Eocene?).
   Rhyolitic tuffs and sands.
2. Hornblende-pyroxene-biotite aleutite.
3. Pyroxene basalt
   Pyroxene olivine-diabase porphyry (dike). (Pleistocene.)

Coso Range.—According to Mr. Fairbanks,[1] the following is the succession of lavas in this range, roughly stated:

1. Rhyolites and andesites.
2. Basalts.

[1] Am. Geol., Vol. XVI, February 1896, p. 73.

Daggett or Calico region.—Southward, in the middle of the Mojave Desert, at Daggett, or Calico (which is on the Mojave River and also on the Santa Fé Railway), great masses of rhyolite have been described,[1] underlying the borax-bearing lake beds which are probably, in part at least, Upper Eocene. These rhyolites are plainly the same as those in the Coso Range and in the Randsburg region.

SUCCESSION OF LAVAS IN THE GREAT BASIN REGION IN GENERAL

In the field it is evident that the same lavas occur in many different localities throughout the Great Basin region, in much the same relative quantity, having nearly the same mineralogical composition, and giving evidence of about the same relative age. Moreover, where two or more of these lavas are found close together, their order of succession is found to be in general nearly the same, although at any given place certain members of the series may be lacking. In no single locality has the complete succession, as indicated by the correlation of all the different sections, been observed; but in order to find it we may fill gaps in one place from the observations in another. In correlating similar lavas erupted at different points, we must consider not only the succession but the relative age of each, so far as this is known. The evidence of this age will be briefly outlined later on; it is with this in mind, however, that the following table has been made. Many of the correlations are only provisional, and will probably require adjustment and rearrangement as the result of future investigation; but it is believed that the general deductions are correct.

By this correlation we see that the succession of lavas seems to have been roughly uniform over the whole region, although minor variations have been numerous at many points. In general, it appears possible to divide the lavas into five groups, in the order of their eruption, as follows:

1. Acid (type, biotite rhyolite).
2. Siliceous intermediate (medium andesites).

[1] W. H. STORMS: Eleventh Rept. State Mineralogist California, p. 347. Sacramento, 1893.

3. Acid (rhyolites with composition like 1) with occasional connected basalts.
4. Basic intermediate (more basic andesites and aleutites).
5. Basic (basic basalts), frequently with closely connected rhyolites.

CORRELATION OF LAVA GROUPS IN POINT OF AGE

The absolute age of the different Tertiary lavas is not easy to find out, although in many special cases it may be done with a fair degree of accuracy. The most recent eruptions are naturally the most easy of determination, while those more remote are more obscure.

1. *Acid.*—In the Pine Nut and Sweetwater ranges the definite age of the older rhyolites is uncertain, but they are separated from the great bodies of massive hornblende-pyroxene-biotite andesite, which itself antedates the Pliocene Shoshone Lake, by a long period of erosion. These rhyolites are also affected by a sheeting which is not found in the andesites, and which indicates crustal disturbance between the eruption of the two lavas.

The observations concerning the Pine Nut and Sweetwater ranges are in general true, also, for the Reveille, Quinn Canyon, and Grant ranges.

In Meadow Valley Canyon the basal rhyolite, with its overlying tuffs, is folded and separated by a marked unconformity from the andesitic lavas and tuffs which succeed. The rhyolite tuffs are roughly estimated at 4000 feet thick, and mark a long period of Tertiary sedimentation, which intervened between the rhyolites and the andesites.

In the Silver Peak region rhyolites are interbedded in portions of the Tertiary lake sediments, which are probably late Eocene or early Miocene.[1]

In the Panamint Range, in the Randsburg district, and near Daggett in the Mojave Desert, lake beds which are probably in part at least Upper Eocene overlie the basal rhyolite.

In general, therefore, it may be said that the age of the rhyolite, which is the first member of the general succession,

[1] H. W. TURNER: The Esmeralda Formation. Am. Geol., Vol. XXX, March 1900, p. 168.

varies in different portions of the petrographic province from early to late Eocene. Strict contemporaneity is not to be expected, but only broad correspondence.

2. *Siliceous intermediate.*—In the region of the 40th Parallel Survey, Mr. King[1] considered that the beginning of Miocene time came between the main period of the hornblende andesites (No. 2 of the succession here outlined) and that of the augite andesites (No. 4 of this succession). Mr. King found his Miocene beds (sediments of the Pah-Ute Lake) largely made up of tuffs derived from what was at that time regarded as trachyte, and he therefore considered the trachytic period as Miocene. The trachytes of the 40th Parallel Survey have been shown to be mainly andesites, in part hornblende-mica andesites and in part pyroxene andesites.[2]

In the Virginia, Pine Nut and Sweetwater ranges, the hornblende-pyroxene-biotite andesites were erupted and eroded previous to the formation of the Shoshone Lake, to which they formed the shores. The Shoshone Lake probably existed in late Pliocene and earliest Pleistocene time; this puts back the age of these andesites to at least early Pliocene.

In the Silver Peak region andesites occur, together with abundant andesitic tuffs, in portions of the Esmeralda formation, which is probably late Eocene or early Miocene.

In the El Paso Range, according to Fairbanks, andesite occurs as interstratified sheets in the late sediments of the Upper Eocene.

Taken altogether, it may be said that the period of eruption of the medium-siliceous andesitic lavas was chiefly in the Miocene, although it probably ran back to the Upper Eocene. The periods of eruption No. 1 and No. 2 therefore overlap, and they are actually found close together in certain of the Upper Eocene lake sediments.

Acid.—Concerning the age of the third member of the succession there are somewhat better data. In the 40th Parallel

[1] Explorations of the 40th Parallel, Vol. I, p. 692.

[2] HAGUE and IDDINGS: Volcanic Rocks of the Great Basin. Am. Jour. Sci., 3d series, Vol. XXVII, January 1884, p. 456.

region Mr. King[1] notes that the rhyolites and rhyolite tuffs seem to be Pliocene. In the Eureka district Mr. Hague[2] came to the same conclusion as regards the rhyolite there.

In western Nevada rhyolities are found interbedded and therefore contemporaneous with the sediments of the late Pliocene Shoshone Lake in a number of localities, as, for example, on the borders of the Pine Nut Range. The same relation to the Shoshone Lake beds was noted on the western edge of the Ralston Desert.

In the mountains near Candelaria glassy rhyolite overlies the folded Upper Eocene or Lower Miocene of the Esmeralda formation. The folding which has affected these beds is the same as that which has upturned the Miocene further north, called by King the Truckee Miocene; so the disturbance must have been late Miocene or post-Miocene. The rhyolite in this case, therefore, is probably as young as the Pliocene.

In the Sierra Nevada Mr. Turner[3] referred the rhyolites to the Upper Miocene. According to Mr. Lindgren[4] the rhyolitic flows of the Sierra in the Truckee region began "toward the close of the Miocene."[5]

In general, therefore, the age of the second chief rhyolite eruption ranges from late Miocene well into the Pliocene.

Basic intermediate. — In the Sierra Nevada, according to Turner,[6] the pyroxene andesite is Pliocene.

[1] Explorations of the 40th Parallel, Vol. I, p. 694.

[2] Mon. U. S. Geol. Surv., Vol. XX, p. 232.

[3] Igneous Rocks of the Sierra Nevada, JOUR. GEOL., Vol. III, No. 4, May-June 1895, p. 406; Auriferous Gravels of the Sierra Nevada, Am. Geol., June 1895, p. 372.

[4] Truckee folio, U. S. Geol. Surv., p. 3.

[5] The writer was at first inclined to correlate the rhyolite of the Sierra Nevada with the earliest rhyolite shown in the general correlation table (No. 1 of the general succession); but a number of considerations, among others that of the comparatively slight age of the Sierra Nevada rocks, as given above, induced him to class them with later rhyolites (No. 3 of the general succession). In agreement with this conclusion are Hague's views (Mon. XX, U. S. Geol. Surv., pp. 261, 281.

[6] Age and succession of the Igneous Rocks of the Sierra Nevada, JOUR. GEOL. Vol. III, June 1895, p. 408.

In the Sweetwater Range, near Wellington, pyroxene andesite flows are found intercalated with the sediments of the great Pliocene Shoshone Lake.

In the Schell Creek, Antelope, and Snake ranges the pyroxene aleutite, which overlies glassy biotite rhyolite, has filled up valleys which are probably early Pliocene, and has suffered only slight erosion, resulting in the development of a narrow Pleistocene valley, since that time. It can hardly, therefore, be older than late Pliocene.

On the whole the main period of eruption of the basic intermediate lavas appears to have been during the Pliocene, and chiefly the late Pliocene. Most of the great andesitic breccias, indicating widely distributed explosive eruptions, seem to belong to this period.

5. *Basic.*— In the Eureka district it is suggested that the latest outbursts, which were of olivine-basalt, occurred in the Pleistocene.[1]

Near Steamboat Springs, which is just west of the southern end of the Virginia Range and in the immediate district of the Comstock lode, the writer observed that the olivine-basalt is probably early Pleistocene, since it has filled the valleys and covered the scarps eroded by the late Pliocene and early Pleistocene Shoshone Lake.

On the borders of the Pine Nut Range the basalt appeared after the Shoshone Lake had shrunk to the later Pleistocene Lake, and after the country exposed by this recession had been partly dissected into canyons. It is therefore plainly of Pleistocene age.

In the Ralston Desert and in the Reveille and Pancake ranges the basalt overlies the Pliocene sediments, supposed to belong to the Shoshone Lake period. In the Quinn Canyon and Grant ranges the basalt has been poured out into valleys which were probably formed in the late Pliocene period.

In most of the other localities where this lava has been found there is little doubt that the age is Pleistocene, although some of the eruptions may date back to the late Pliocene.

[1] Mon. U. S. Geol. Surv., Vol. XX, p. 232.

TABULATION

The relative age of the different members of the volcanic section, therefore, may be roughly outlined in the following table. It must be remembered that this is only approximate.

The age of the members of volcanic succession being determined, we can sometimes apply this determination in cases where the age of the lavas cannot be independently ascertained, and use them roughly as time markers.

Epochs of sedimentation	Standard time divisions	Epochs of vulcanism
	End of Cretaceous	No. 1. Acid (type, biotite rhyolite)
Eocene-Miocene Lakes	Eocene	
	Miocene	No. 2. Medium intermediate (type, hornblende-mica-pyroxene andesite)
		No. 3. Acid (type, biotite rhyolite)
Shooshne Lake	Pliocene	No. 4. Basic intermediate (types, pyroxene, andesite, etc.)
Lake Lahontan	Pleistocene	No. 5. Basic and acid (basalts and occasional rhyolites)
Walker Lake, etc.		

LAW OF SUCCESSION OF LAVAS

The most natural deduction from all these harmonious observations is that the Great Basin, southward into the Mojave Desert, together with a portion at least of the Sierra Nevada, constitutes a petrographic province; that is to say, it is underlain by a single body of molten magma, which has supplied, at different periods, lavas of similar composition to all the different parts of the overlying surface. The limits of this subcrustal basin, however, are not yet defined in any direction.

In studying the eruption of different lavas from this magma basin at different periods, it is instructive to inquire whether or not the succession follows any definite laws. Mr. Iddings[1] interpreted the usual law of succession in volcanic rocks as this: that a series begins with a rock of average composition, and passes through less siliceous and more siliceous ones to rocks extremely high in silica and others extremely low in silica—that is, the series commences with a mean and ends with extremes. This interpretation of Iddings was based on his work in the Yellowstone Park and vicinity, at Eureka, Washoe, and elsewhere. From studies of the eruptive rocks in the vicinity of Christiania Professor Brögger also thought to have determined a definite law of succession, by which the lavas progress from the most basic to the most acid varieties. Sir Archibald Geikie,[2] from a study of igneous rocks in Great Britain, has come to the same general conclusion as to the succession.

The section of Tertiary volcanics exposed at Eureka and Washoe, as given by Mr. Hague, begins with what is designated by the present writer No. 2 in the succession, and does not reach back to the basal biotite rhyolite. The general succession for the Great Basin, leaving out this basal rhyolite, appears, then, to be as follows:

2. Siliceous intermediate.
3. Acid (and basic).
4. Basic intermediate.
5. Basic (and acid).

[1] The origin of igneous rocks, Bull. Phil. Soc. Washington, Vol. XII, p. 145.

[2] Quar. Jour. Geol. Soc. Lond., 1892, Vol. XLVIII, p. 177.

Under No. 5 we find the very basic olivine-basalts and very siliceous rhyolites or tordrillites, erupted at the same period and evidently connected by the closest ties. This, for example, was observed to be the case in the Pleistocene volcanics of the Meadow Valley Canyon, and the same is true in the basin of Lake Mono, according to Russell.[1]

These closely allied ultra-basic and ultra-acid lavas are plainly complementary forms, and are proofs of differentiation as convincing as are the complementary segregations so familiar in single masses of intrusive or plutonic rocks.

Going a little further, if we write Nos. 3 and 4 of this last succession together and precede it by No. 2 (which we may divide into two members) we have the following grouping:

2. { Medium andesite.
   { Acid andesite and dacite.

3. { Acid rhyolite (with basalt).
4. { Medium basic andesite.

5. { Basalt.
   { Acid rhyolite.

We have here, therefore, a series (apparently conformable to Iddings' law) which begins with a rock of intermediate composition and progresses to extremes, as a result, probably, of differentiation.

But the first member in the order of succession as interpreted by the writer, viz., the basal rhyolite, is apparently out of place in this scheme. This rock has a composition essentially like the later rhyolite, but appears to have no immediate connection, mineralogically or chemically, with the andesites which form the base of the Eureka lavas. The andesites can hardly be derived from the rhyolites by any hypothetical differentiation, and even in that case the order seems in direct opposition to all of the hitherto propounded laws of succession.

It was first, therefore, the conclusion of the writer that the law deduced by Iddings would not hold good in the Great Basin, on

[1] Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Surv., Part I.

account of the basal rhyolite. From further study, however, the evidence of differentiation up to this point appears to be so good that he is inclined to accept it, and to consider the basal rhyolite as belonging to a different order of events.

This basal rhyolite is, in chemical and mineralogical composition, much like the latest rhyolite, No. 5, in the writer's order of succession. Like it, it often becomes extremely siliceous. From this circumstance, and from the apparent break in composition between the rhyolite No. 1 and the andesite No. 2, the writer conceived the idea that the two rhyolites are *recurrent* lavas—that is, that they represent a similar development in distinct but similar processes of differentiation. The development of lavas might then be interpreted as follows:

1. Acid rhyolite.
   Revolution and beginning of new epoch.
2. Medium to acid andesite and dacite.
3. Acid rhyolite (with basalt).
4. Medium basic andesite.
5. { Basic basalt.
   { Acid rhyolite.

In case this is the current grouping, it is probable that No. 1 represents the end product of a differentiation, and is similar to the rhyolite under No. 5; and that 2 to 5 inclusive represent an independent differentiation process.

The difficulty with the above arrangement is, first, the olivine-basalt, which we are obliged to couple with the rhyolite under No. 3. The existence and relations of this basalt in the Sierra Nevada seems to be well established. The second difficulty arises from the fact that the rhyolite No. 3 is of exactly the same acid type as the rhyolites under 1 and 5. From this fact the idea originates that rhyolite No. 3 may be also a recurrent lava, and that we have in the whole volcanic succession portions of three instead of two cycles of differentiation.

On testing this hypothesis we are struck with the fact that andesites 2 and 4 have identical phases, although the groups as a whole differ as stated in the above list. At Eureka the earlier and later andesites were held to be separate, the earlier ones

being more siliceous and not approaching the later ones more nearly than by 2.25 per cent. of silica.[1] At Washoe, however, the pyroxenic andesites, which precede the more siliceous andesites representing at Eureka the earlier group, become equally basic with the andesites of the second period. In other portions of the Great Basin also the andesites belonging to the first and second periods are often indistinguishable.

On studying the general succession, as partially set forth in the table of correlations, we find that the break between Nos. 3 and 4 in the succession is as abrupt as that between Nos. 1 and 2. On the other hand, between 2 and 3 there are many transitional phases, and also between 4 and 5.

We may represent the facts above noted, graphically, as follows:

1. Rhyolite.
2. Andesite.
3. Rhyolite (and basalt).
4. Andesite.
5. Basalt (and rhyolite).

The break between 3 and 4 was noted by Mr. Hague at Eureka.[2] He ascribed it to a change of magmas and argued that the first members of the succession at Eureka, beginning with hornblende andesite and ending with acid rhyolite, were derived from a magma distinct from that which produced the later members of the succession, beginning with pyroxene andesite and ending with basalt. In the first group Mr. Hague found, between the andesite and the rhyolite, gradual transitions which grew continually more siliceous; likewise in the second group he found gradual transitions between the pyroxene andesite and the basalt. This implies two distinct processes of differentiation, the first of which proceeded from intermediate to acid, while the second followed the opposite order, from intermediate to basic. Mr. Hague's interpretation of the development of lavas at Eureka may be graphically represented as follows:

[1] Monograph XX, U. S. Geol. Surv., p. 269.

[2] Monograph XX, U. S. Geol. Surv., pp. 254, 269, 270, 271.

Feldspathic Magma	HORNBLENDE ANDESITE. ↓ ACID RHYOLITE.	Series growing gradually more siliceous.
Pryoxenic Magma	PYROXENE ANDESITE. ↓ BASALT.	Series growing gradually more basic.

The *general* succession in the Great Basin region, as set forth in the table which we have made opposite this page, corresponds to Mr. Hague's conception (leaving out of the question the rhyolite No. 1, which is not exposed in the Eureka district). The relations of the lavas of the whole region, therefore, omitting the minor exceptions, might be represented as follows:

1. RHYOLITE.

Break.

2. ANDESITE.

↓ Gradual transitions.

3. RHYOLITE.

Break.

4. ANDESITE.

↓ Gradual transitions.

5. BASALT.

Nevertheless, the exceptions are frequent enough to demand recognition. Observations at several points outside of the Eureka district prove that basalt No. 5 has a closely associated rhyolite which is plainly complementary. Similarly, rhyolite No. 3 has in the Sierras an associated olivine-basalt, which is also probably complementary. Upon looking carefully, we find that there are complementary phases for the stages intermediate between the andesite No. 4 and the basalt No 5; and we become

	Gabb's Valley	Ralsto
		Rhyoli Tordri
:-	Biotite andesite	
	Biotite rhyolite	Rhyoli
s, e	Hypersthene-hornblende aleutite	
	Augite basalt	Olivine-

aware that these complementary forms constitute an acid-growing series, transitional between the andesite No. 4 and the rhyolite which is complementary with No. 5, and that this series appears to be in general contemporaneous with the basic-growing series between the andesite and the basalt. As an example of this acid-growing series consecutively observed, the section described in Meadow Valley Canyon is highly interesting; here we have a transition from pyroxene andesite through intermediate phases to Pleistocene rhyolite, which is complementary with Pleistocene basalt.

Between the andesite No. 2 and the olivine-basalt which is coupled with the rhyolite No. 3, we have not found such satisfactory transition phases, but this is perhaps due to the remoter age of this group of lavas.

We may, therefore, write the general succession and relation of the lavas of the Great Basin, as follows:

1. BIOTITE RHYOLITE AND TORDRILLITE.

2. PYROXENE-HORNBLENDE ANDESITE.
   Hornblende-pyroxene andesite.
   Hornblende andesite.
   Biotite andesite.
   Hornblende quartz-andesite. — Pyroxene andesite (?)
   Dacite.
   Latite (?)[1]

3. BIOTITE RHYOLITE. — OLIVINE-BASALT.

[1] Compare some of the analyses of the earlier andesites and dacites at Eureka (e. g., Mon. XX, U. S. Geol. Surv., p. 264, Nos. 4, 5, and 6), with those of latites given by DR. RANSOME (Bull. 89, U. S. Geol. Surv., p. 66).

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1. BIOTITE RHYOLITE AND TORDRILLITE.

2. PYROXENE-HORNBLENDE ANDESITE.
   - Hornblende-pyroxene andesite.
   - Hornblende andesite.
   - Biotite andesite.
   - Hornblende quartz-andesite. — Pyroxene andesite (?)
   - Dacite.
   - Latite (?)[1]

3. BIOTITE RHYOLITE. — OLIVINE-BASALT.

[1] Compare some of the analyses of the earlier andesites and dacites at Eureka (e. g., Mon. XX, U. S. Geol. Surv., p. 264, Nos. 4, 5, and 6), with those of latites given by DR. RANSOME (Bull. 89, U. S. Geol. Surv., p. 66).

aware that these complementary forms constitute an acid-growing series, transitional between the andesite No. 4 and the rhyolite which is complementary with No. 5, and that this series appears to be in general contemporaneous with the basic-growing series between the andesite and the basalt. As an example of this acid-growing series consecutively observed, the section described in Meadow Valley Canyon is highly interesting; here we have a transition from pyroxene andesite through intermediate phases to Pleistocene rhyolite, which is complementary with Pleistocene basalt.

Between the andesite No. 2 and the olivine-basalt which is coupled with the rhyolite No. 3, we have not found such satisfactory transition phases, but this is perhaps due to the remoter age of this group of lavas.

We may, therefore, write the general succession and relation of the lavas of the Great Basin, as follows:

1. BIOTITE RHYOLITE AND TORDRILLITE.

2. PYROXENE-HORNBLENDE ANDESITE.
   - Hornblende-pyroxene andesite.
   - Hornblende andesite.
   - Biotite andesite.
   - Hornblende quartz-andesite.
   - Dacite.
   - Latite (?)[1]
   - Pyroxene andesite (?)

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PYROXENE-HORNBLENDE ANDESITE.

4.	Pyroxene andesite.	Hornblende-pyroxene andesite.
	Hornblende-pyroxene-biotite aleutite.	Augite-biotite-hornblende latite.
	Hypersthene-hornblende aleutite.	Biotite-augite-hornblende quartz-latite.
	Pyroxene aleutite.	Biotite-hornblende dacite.
	Pyroxene olivine-aleutite.	Hornblende-biotite latite.
5.	Hornblende basalt.	Biotite-hornblende rhyolite.
	Augite basalt.	Biotite rhyolite.
	OLIVINE-BASALT.	ULTRA ACID RHYOLITE OR TORDRILLITE

It therefore appears that we have the representatives of two complete cycles of differentiation, and probably the end of a still earlier cycle. During the first completely recorded cycle (beginning with the earlier andesites) the more siliceous rocks were continually extravasated in preference to the more basic complements, so that the acid-growing series is far more prominent in the record than the basic-growing one. On the contrary, during the second or last complete cycle the more basic rocks were continually thrown out in preference to the more siliceous ones, making the basic-growing series more prominent. The laws which govern these apparently eccentric preferences of eruption are yet unknown.

I have looked in vain in the field for the earlier representatives of the first cycle of differentiation, to which No. 1 belongs. If they were erupted previous to the appearance of the rhyolite (No. 1) they have not yet been determined.[1]

[1] What may possibly be one of the members of the earlier differentiation cycle, older than the rhyolite, occurs in the Walker River Range. Here the granite and alaskite, which are considered by the writer as probably the deeper-seated equivalents of the basal rhyolite of the Great Basin section, are evidently younger than and at times intrusive into a great body of biotite-hornblende quartz-monzonite. A similar hornblende-biotite quartz-monzonite was found east of the Walker River Range, in Gabb's

Reasoning on the basis of the deductions specified, we may speculate briefly concerning the cause of the two revolutions, the reappearance of the intermediate magma, and the exhaustion of the old, highly differentiated magmas. In explanation of this, the hypothesis may be advanced that magma basins or lava reservoirs may be almost entirely exhausted by the expulsion of lavas to the surface, and that this emptying may permit refilling by new material from lower regions.[1] It is very possible that the processes of differentiation can only go on under certain circumstances, such as are probably afforded by the comparatively quiet magma basins, and that in the lower regions there may be so much mixing that segregation is impossible.[2] Therefore, when the magma basin is exhausted and receives a new supply from below, it is of material similar to that which filled the basin before differentiation altered it. It is probable that in this way the history of many petrographic provinces, when closely studied far back into geologic time, will be found to be not a simple, single process, but a succession of several or many differentiation cycles, some of which will probably be found to be complete, and some interrupted by this or that accident. It is probable that the existence of recurrent lavas will be found true at many points.[3] In Alaska the writer has found that the

Valley, and here was considered to be extrusive. The writer's grounds for considering that the Walker River Range granite is equivalent to the basal rhyolite cannot be given in this paper, but will appear subsequently. If they prove sound, then the older monzonite very likely represents a pre-rhyolitic monzonitic effusive rock, or at least a less siliceous pre-rhyolite magma.

[1] Since writing the above the writer has chanced upon the following sentence of IDDINGS ("Origin of Igneous Rocks:" Bull. Phil. Soc., Washington, Vol. XII, 1892–4, p. 179): "It is also possible to find a recurrence of different varieties at one center of eruption, which may be accounted for by supposing successive supplies of magma from some depth, which differentiate into similar varieties before their final eruption," He also finds that the same idea had been previously expressed by Sir Archibald Geikie (Quar. Jour. Geol. Soc., London, Vol. XLVIII, 1892, p. 178), as follows: "And as the successive protrusions took place within the same circumscribed region, it is evident that in some way or other, during the long interval between the two periods, the internal magma was renewed as regards its constitution, so that when eruptions again occurred they once more began with basic and ended with acid materials."

[2] IDDINGS (op. cit., p. 196) considers that the general or undifferentiated magma remains undifferentiated on account of being solid, that is, being in a state of potential liquidity.

[3] GEIKIE (op. cit.) in his study of the history of volcanic activity in Great Britain

probably Silurian basalt or basaltic diabase of the Rampart series is identical in composition with the olivine-basalts of the Pliocene.[1] Yet between these two periods a great variety of volcanic rocks, including other basalts, appeared in Alaska.

In studying the succession of lavas it must be borne in mind that the processes of differentiation are quite independent of the causes which produce the expulsion of lavas. Therefore, while the differentiation in a magma basin may go on so that all intermediate types between the initial intermediate one and the final extremes are represented, yet the causes producing eruption will probably occur only at different points in this process, so that the record will be only partial and perhaps not to be interpreted except by comparison with other localities. For this reason, the observed succession must be studied with regard to its general aspects rather than to its details. In interpreting the succession, also, the possibility, or even probability, of many intermediate forms being brought about by accidental mixing during the general processes of differentiation, must be borne in mind. This error may be eliminated if at each period of vulcanism we select the extreme important types, omitting the associated intermediate ones as possibly formed by mingling. The variations introduced by mingling and those brought about by irregular volcanic eruptions are such that it is difficult to apply to them any law. It has been assumed, for example, that in general basalts overlie rhyolites where these occur close together. This is held by Messrs. Hague and Iddings[2] as well as by previous observers. But Marvine[3] observed, in the Colorado River region, basalt lying upon rhyolite, and the present writer observed the same relation in the Pleistocene lavas of Meadow Valley canyon, which is a part of the drainage of the Colorado.

J. E. Spurr.

from the earliest pre-Cambrian times to the Tertiary, has found that similar rocks recur at many different points in the succession. He finds also similar series, so that he is led to divide the whole succession into natural groups or periods of volcanic activity. See also Iddings, op. cit., pp. 145, 179, 196.

[1] Geology of the Yukon Gold District. Eighteenth Ann. Rept., U. S. Geol. Surv., Part III, Economic Geology, p. 241.

[2] Mon. U. S. Geol. Surv., Vol. XX, p. 86.

[3] U. S. Geol. Surv., W. 100th Mer., Part III, p. 205.

THE GLACIER OF MT. ARAPAHOE, COLORADO

On the fourth day of August 1900, I was one of a party of seven men who ascended Mt. Arapahoe. This mountain is the highest of a small group of peaks on the Continental divide in Colorado. It is situated about latitude 40° 1′ N. and longitude 105° 38′ W.[1] and has an elevation of 13,520 feet above sea level. There are several peaks of nearly equal altitude in the group, but they are so intimately connected that they form practically one mountain. The group is locally known as "The Arapahoes." The peaks, together with their spurs and connecting ridges, nearly encircle a large enclosure in which the north branch of Boulder Creek rises. In the southern part of this enclosure is a well-defined cirque which is partitioned off by a spur extending into the enclosure from the side of the highest peak. This spur forms the north wall of the cirque. Its west and south walls are formed by Arapahoe Peak proper and the peak next south, together with their connecting ridge, which is but little lower than the summit of the peaks. The east wall is formed by a third peak, the summit of which is a few hundred feet lower than the other two and joined to the peak on the south side by a moderately high ridge. The cirque opens toward the northeast by a constricted passage into Boulder Creek valley.

The inner slopes of the cirque are precipitous on all sides. In only a few places can they be climbed in safety. The accompanying photograph, Fig. 1, taken from a high point and looking downward, does not adequately represent the degree of slope. The south wall is, in places, nearly vertical. The naked cliffs rise something like 1000 feet in the clear. But at the southwest and west sides the slopes are such that great masses of snow and ice of unknown depth lie upon them, reaching from the main mass at the bottom of the cirque, to the top of the ridge. The largest of these arms is shown in

[1] HAYDEN's atlas of Colorado.

FIG. 1.—View of the Arapahoe glacier from below.

the illustration Fig. 1. The peak with its perpendicular cliffs forming the south wall, together with about one third of the cirque, is cut off from view by the bluff in the foreground. Figure 2 is a near view of this peak showing the upper extremity of one of these arms of snow and ice.

The cirque presents exceptional advantages for the accumulation and preservation of snow and ice:

1. The encircling peaks and ridges are barriers behind which the drifting snow accumulates during the winter. From whatever direction the wind blows, except from the northeast, its velocity is checked by the peaks and ridges forming the walls of the cirque, and the cirque receives its burden of snow. The importance of this mode of accumulation is well illustrated in the long snow drifts which are common along the high ridges throughout the mountains where the winds have dropped their burden in the lee of the crests. In some instances the summer's heat is not sufficient to melt away these drifts even where they lie exposed to the sun on the south side of the ridges.

2. The snow and ice of the cirque are more or less protected from the heat of the sun, by the elevated rim which is highest, and the inner slope steepest, on the south and west sides. On these two sides where the slope is gentle enough to permit it, lie accumulations of snow and ice of unknown thickness, extending from bottom to top of the walls. On the northern side, *i. e.*, the southern slope of the spur, the snow and ice reach but a little way up the side. This may be due in some measure to a difference in the amount of accumulation of snow, but it is certainly due primarily to the greater melting power of the sun on the slope facing southward.

3. The snow and ice of the cirque are also protected by sheltering from the east, south, and west winds. While our party was on one of the peaks overlooking the cirque, a thunder storm from the southwest enveloped the mountain. After the wind had swept the clouds from the southwestern side of the mountain, the cirque remained full of thick mist. The wind which was blowing at a moderately high rate of speed, cut off

FIG. 2. The south peak of the Arapahoes, showing the upper extremity of one of the smaller arms of the glacier.

the cloud mass even with the crests of the ridges, and passed completely over the cirque instead of descending into it in any notable measure, and sweeping the mist away. For nearly half an hour after the clouds had been swept away from the windward slope of the mountains, the cirque was more or less obscured by shifting and eddying mists. These were at first parts of the original cloud. Later they were mists formed within the cirque. The latter formed the better index to the action of the winds. From their behavior it was evident that only secondary air currents came in actual contact with the snow and ice of the cirque.

Within the cirque the snow and ice are nearly all collected into two masses. These seem to be essentially independent of each other, and are separated by a ridge of débris. To the east of this ridge is the smaller of the two. To the west of the ridge is the larger—the main mass of snow and ice of the cirque. The larger field was estimated to be nearly two miles wide. Its length seemed to be approximately the same but I was not in a position to make a satisfactory estimate of the length. Its surface is steeply inclined. In several places where the snow and ice extends to the top of the south wall, we measured the inclination of its surface from above as carefully as possible by holding one climbing staff vertically and sighting down the slope with another. The angle thus given showed an inclination of about fifty degrees. At these points the upper edge which had been melted back at its contact with the cliffs, showed a thickness of twenty to forty feet. Over the bottom of the cirque the slope of the surface of the ice is gentle enough for small bowlders from the cliffs above to lodge on it. This gentler slope was somewhat thickly covered in places with stones and small bowlders. No large bowlders were seen on the surface, but below the lower edge of the ice, are great numbers of rock-masses, ten to twenty feet in diameter or even larger. It is probable that the large bowlders gain momentum enough on the steep slopes above to carry them over the gentler slopes and beyond the edge of the ice

The ice is hard and compact to the surface. Bowlders weighing two hundred or three hundred pounds were rolled down the slopes but made little impression on the surface of the ice. A small lake fifteen feet across and four feet deep was found on the surface. Late in the afternoon I found that the ice had softened scarcely enough during the day to prevent me from slipping even on comparatively gentle slopes.

The mountaineers who are familiar with the Arapahoes, had warned us against descending over the ice on account of crevasses. An opening seen about five hundred feet below the top of the ridge and which appears as a broken line in the illustration (Fig. 1) is presumably a crevasse. Others were seen from a distance which were not so well defined: I had no opportunity for close inspection. The mountaineers gave me somewhat careful descriptions of the openings, and told of a man who had been lost presumably in a crevasse. Their search for him resulted in finding nothing but his overcoat. From the descriptions given by these men, and from what I saw of the snow and ice, I am convinced that true crevasses are to be found there.

The stratified nature of the ice is seen along the steep face of its lower edge. Dark bands, probably due to the accumulation of foreign material on the surface during the summer, alternate with lighter bands. Some of the individual bands were traced, with the aid of the field glass, for long distances. Only the uppermost of these bands can be distinguished in the accompanying photograph. This is seen as a light line along the upper edge of the face of the ice, and is due to the whiteness of last winter's snow. On the surface of the ice at the right and a little way back from the edge, is a dark spot where the fresh white snow has been removed from the darkened surface of an older accumulation.

Along the base of the eastern rim of the cirque, a relatively small amount of snow and ice accumulates to form the smaller field. Its tendency to movement indicated by the slope of its surface, is diagonally opposed to that of the greater mass moving from the west and south. Over the surface of this smaller

mass I descended for about a mile but discovered no unquestioned evidences of movement of the ice. Between this and the edge of the greater mass to the west, a large ridge of débris has been formed. The ridge is inconspicuous at its inception near the upper end of the smaller ice field, but farther down it increases in size until near the outlet of the cirque it assumes notable proportions. In former times the upper part of this ridge now separating the two snow fields, was probably a medial moraine. But the recession of the ice has changed it into a terminal moraine throughout the greater part of its length. The ridge is crescent shaped and conforms rather closely to the edge of the ice. It has two more or less distinct crests—an outer large one, and an inner small one. Between the smaller crest and the edge of the ice, is a well defined trough.

There is a shallow lake a short distance below the edge of the ice. From an eminence on which I stood looking down upon this lake, I noticed that the current, produced by the stream flowing into it from the ice above, could be plainly traced for several rods by its whiteness which was presumably due to the rock flour derived from the ice above. This was not present in sufficient quantity to attract my attention in the running stream. But the contrast in color as the whitened water of the stream entered the green water of the lake was conspicuous. Closer inspection strengthened the conclusion that the stream carried rock flour.

The size of the ice mass; its great though unknown depth; the steep inclination of its surface; its stratification and crevasses; its terminal moraine; and the rock flour of its stream, all point to the inference that this field of snow and ice constitutes a true glacier.

The valley into which the cirque opens is one of broad bottom and precipitous sides. The side walls are nearly vertical in many places. Its floor is occupied by a chain of lakes interrupted in several places by groups of poorly formed roches moutonnées. Most of the lakes are in rock-hewn basins, but some are formed back of débris dams. One in particular, near

the head of the valley, is a beautiful example of the latter. It rests behind a crescent shaped ridge—a comparatively recent terminal moraine. Fragments of terminal moraines extending partly across the valley bottom, occur in several places near the head of the valley.

Résumé.—1. The exceptional amount of snow and ice in the cirque at Mt. Arapahoe is due to the unusual advantages presented for its accumulation and preservation. These consist (*a*) in trapping the drifting snow, and (*b*) in protecting it from sun and warm winds. 2. Within the cirque are two fields of snow and ice which are essentially independent of each other at the present time. The larger field is estimated to be something like two miles in width and about the same in length. 3. The snow and ice of the larger field constitutes a glacier. This is attested (*a*) by the amount of snow and ice there accumulated, and by the inclination of its surface which varies from about 10° to 50°; (*b*) by its stratification indicated by the banding of the face; and (*c*) by its movement, indicated by the crevasses, the moraines, and the rock flour. 4. This glacier is the survivor of a much larger glacier which formally occupied the upper part of Boulder Creek valley.

WILLIS T. LEE.

THE SHENANDOAH LIMESTONE AND MARTINSBURG SHALE[1]

INTRODUCTION

WHILE engaged in fieldwork on the Maryland Geological Survey, the writer has had an opportunity to examine to some extent the upper part of the Shenandoah limestone and the overlying Martinsburg shales.

Shenandoah limestone.—The name Shenandoah was proposed by Mr. Darton in 1892 for the limestones of the Shenandoah Valley and the formation was described in the vicinity of Staunton, Va., as consisting of "a great mass of impure magnesian limestones below, grading upwards through a series of cherty beds of no great thickness into several hundred feet of light-colored, heavily bedded purer limestones. The lower beds were not found to be fossiliferous. In the cherty beds only a few middle Ordovician gasteropods were found. . . . . The upper member is sparingly fossiliferous at many localities with a middle to upper Ordovician fauna in which the forms *Orthis occidentalis*, *O. testudinaria*, *Leptæna alternata*, and *Chætetes lycoperdon* were predominant. *Pleurotomaria subconica*, *Conularia trentonensis*, *Platynotus trentonensis*, and several others were also noted."[2]

Mr. Darton in his account of this formation in the Staunton folio described an upper member of the limestone from 200 to 350 feet in thickness which is said to be purer, more thickly bedded and generally of lighter color than the older part of the formation. It is also stated that in the upper division "fossils occur also in greater or less profusion throughout its course. The fauna is that of the Trenton limestones of New York."[3]

Martinsburg is near the northwestern corner of the Harper's Ferry sheet which was mapped by Mr. Arthur Keith,[4] and the

[1] Published by permission of Dr. Wm. Bullock Clark, State Geologist of Maryland.

[2] Amer. Geol., Vol. X, p. 13. [3] Geologic Atlas of the U. S., Folio 14, 1894, p. 2.

[4] Geologic Atlas of the U. S., Folio 10, 1894.

line between the Shenandoah limestone and the Martinsburg shale is clearly shown in the vicinity of that city, but the description of the formation gives no additional information regarding its age.

Professor Wm. B. Rogers considered that the Trenton, Utica and Hudson River formations were represented in the Potomac Valley at Williamsport and to the west; but he apparently regarded the greater part of the limestone as of Chazy, Levis and Calciferous age.[1]

Martinsburg Shale.—The name Martinsburg shale, like that of the Shenandoah limestone, was proposed by Mr. Darton from the exposures near Martinsburg, W. Va., "a region in which," he states, "the formation is extensively and typically exposed." It is stated that at the base there is "a thin series of alternating thin bedded limestones and slates" but for the most part the rocks of the formation "are slates and shales, mainly of dark color. . . . . The beds are fossiliferous at many points; graptolites are found in the basel beds, notably in some light colored weathered shales in cuts of the Chesapeake and Ohio Railway, two miles east of Staunton and further east; along the Little North Mountain, and in the Warm Spring, Crab Bottom and other anticlinal valleys westward, remains of upper Ordovician brachiopoda are moderately abundant. The forms most frequently met with are *Leptæna sericea*, *L. alternata*, *Orthis testudinaria*, *O. pectinella*, and *Modiolopsis modiolaria*. The precise equivalency of the formation is not known, but judging from its general relations and fauna it probably comprises the Utica, Hudson River and possibly small amounts of adjacent formations of the New York series. It is the No. III of Rogers' reports and has generally been called 'Hudson River.'"[2]

Under the description of the formation in the Staunton Folio Mr. Darton states that "In the Jack Mountain exposures fossils are abundant, and the species are of Hudson age," while "In the

[1] See Plate No. VII, Sec. No. 1, in "A Reprint of Annual Reports and other papers of the Geology of the Virginias," edited by Jed. Hotchkiss, 1884.

[2] Amer. Geol., Vol. X, pp. 13, 14.

beds east of Churchville and in the buff and red slates at the base of the formation in cuts two miles east of Staunton, Utica graptolites occur in considerable abundance."[1]

Mr. Keith, apparently, did not have a very clear conception of the lithological character of this formation for he states in his description that "It consists of black and gray calcareous and

FIG. 1.—Parson's quarry in Shenandoah limestone, near Martinsburg, W. Va.

argillaceous shales of fine grain, and shows no variations within this area."[2] It will be seen in the following description that after the thin argillaceous shales in the lower part of the formation there are shales alternating with greenish micaceous sandstones. Again there is confusion in reference to the period to which the formation belongs for in the description it appears under the Cambrian,[3] and under the "columnar section"[4] and legend of the map as Silurian.

[1] Geologic Atlas of the U. S., Folio 14, p. 2.

[2] Geologic Atlas of the U. S., Folio 10, p. 3. [3] *Ibid.*, p. 3. [4] *Ibid.*, p. 5.

DESCRIPTION OF SECTIONS

What follows in this paper in reference to the Shenandoah limestone relates more particularly to the upper part of that formation which was studied to some extent in the vicinity of Martinsburg, West Virginia, and Pinesburg, Maryland.

Limestone and shale near Martinsburg.— 1. Along the Baltimore and Ohio Railroad immediately east of Martinsburg station are exposures of the upper part of the Shenandoah limestone. At the western end of the cut, just east of the railroad bridge over Tuscarora Creek, are dark blue, fairly massive limestones, some of which, however, on weathering split into quite thin, irregular layers (Fig. 1). These limestones are fossiliferous, two species of *Lingula*, together with some other forms having been noticed, and the rocks closely resemble many parts of the typical Trenton limestone of New York. In the eastern part of this cut, near the switchtender's station, there are thin layers of dark blue limestone which alternate with dark blue to black calcareous shales containing fragments of graptolites, and this part of the cut shows a transition from the massive limestones of the Upper Shenandoah to the lower shales of the Martinsburg formation. This part of the section is shown in Fig. 2.

3. To the east of the switch cut the rocks are covered for some distance; but about one half mile east of the station is Cemetery cut, where several hundred feet of quite thin, even, bluish, somewhat argillaceous shales are well shown. These may be seen in Fig. 3. In a rather hasty examination no fossils were found and the lithological character of these shales is rather more like that of the Hudson in New York than the Utica shale.

4. To the east of Cemetery cut is a covered space and then another railroad cut in shale follows. These shales which are mainly blue and arenaceous closely resemble lithologically the Hudson shales of the Mohawk Valley and Eastern New York, and alternating with them are thin layers of greenish, micaceous sandstone similar to those in the lower part of the Hudson in

numerous localities in New York. In the western part of the cut are some rather thin, blackish, argillaceous shales.

In the southern part of Martinsburg, operated by the Maryland Limestone Quarry Company, are extensive quarries in the massive Shenandoah limestone, large quantities of which are

FIG. 2.—Transition from Shenandoah limestone to Martinsburg shale in switch cut on B. & O. R. R. east of Martinsburg, W. Va. The men are standing opposite the upper part of the Shenandoah limestone and the Martinsburg shale is to the right.

shipped to the steel and other furnaces in the vicinity of Pittsburg. The limestone is mainly a light colored drab and this part is reported as the purest and best for flux. No fossils were found in the limited time given to the search and one of the quarrymen said he had never noticed any.

Exposures near Pinesburg, Md.— A number of the exposures in the vicinity of Pinesburg station on the Western Maryland

Railroad in the southern part of Maryland, about thirteen miles north of Martinsburg, proved more fossiliferous than those in the vicinity of Martinsburg.

1. The Pinesburg quarry is on the Western Maryland Railroad, a short distance west of the station. There is an exposure of about fifty feet, the southern and higher part of the quarry furnishing dimension stone which is dark blue to almost black in color with banded layers of blue and bluish-gray and contains fragments of trilobites, crinoid stems and some other fossils, while the northern and lower part is used mainly for ballast. The dip is 20° E. A view of this quarry is given in Fig. 4.

2. A short distance to the east of the quarry is an excavation in massive drab limestone, some of which before weathering is dark in color, but afterward it is all a light gray. Fossils are rare. Several specimens of *Leperditia*, a *Rhynchonella*, a fragment of a *Leptæna* similar to *alternata* and fragments of some other fossils were found.

3. On the railroad, between the quarry and the station, is a small cut through thin bedded, dark blue, compact limestones and some shaly layers. Fossils are common in some of these layers and on one a large number of poorly preserved and crushed specimens of *Asaphus platycephalus* Stokes were found. The complete list of species found in this cut is as follows:

1. *Asaphus platycephalus* Stokes.
2. *Monticulipora* (*Prasopora*) *lycoperdon* (Say).
3. *Calymene callicephala* Green (?).
4. *Lingula rectilateralis* Emm. (?).
5. *Plectambonites sericea* (Sowb.).
6. *Orthis* (*Dalmanella*) *testudinaria* Dal.
7. *Rhynchotrema inæquivalve* (Castelnau) (?).

The rock has been quite badly crushed, but in lithological appearance it closely resembles the Trenton limestone in New York. This limestone ledge is near the top of the Shenandoah formation, for the Martinsburg shales occur only a short distance to the east by the side of the road at the Pinesburg station

and to the east of "Slate Ridge." The weathered shale is a gray to an olive-grayish color and is very argillaceous. It is to be noted that the lower shales of the Martinsburg are argillaceous and calcareous, while the arenaceous ones finally alternating with

FIG. 3.—Martinsburg (Utica) shale in Cemetery cut, on B. & O. R. R., one half mile east of Martinsburg, W. Va.

sandstones, occur higher in the formation. This part of the formation, composed mainly of thin bedded, micaceous, somewhat buff-colored sandstones, alternating with some olive argillaceous and arenaceous shales, may be seen by the side of the highway west of Williamsport, Md., and in the western part of the town.

[illegible]

[illegible]

[illegible] The bluish to black [illegible] which succeed the Shen- [illegible] from the lower part of the Martinsburg

shales closely resemble the Utica shale, and represent that formation.

In that lithological change from the argillo-calcareous shale, the arenaceous deposits of the succeeding portion of the Martinsburg formation agree with the transition from the Utica to the Hudson shales of New York. This arenaceous part of the Martinsburg shale the writer would correlate with the Hudson shales of New York as exposed in the lower Mohawk Valley and the Helderberg region. In the revised list proposed by Clarke and Schuchert for the New York series,[1] Lorraine beds is probably the name of the formation with which these shales should be correlated. It is to be noted, however, that the deposits which have been called the Hudson formation in the Mohawk and Helderberg region do not contain many of the species, or resemble closely in lithological appearance the rocks in the vicinity of Lorraine, New York.

CHARLES S. PROSSER.

COLUMBUS, O.

[1] *Science*, N. S., Vol. X, 1899, p. 876.

REVIEWS

Geology of the Little Belt Mountains, Montana, with notes on the Mineral Deposits of the Neihart, Barker, Yogo, and other Districts; by Walter Harvey Weed; accompanied by a report on *The Petrography of the Igneous Rocks of the District*, by L. V. Pirsson. Twentieth Annual Report of the U. S. Geological Survey, Washington, 1900. Pp. 257–581, with [illegible] plates and [illegible] figures.

Th[illegible] report is based upon field work done in Septem-ber [illegible] and [illegible]. The major part of the report was writ-ten by Mr. Weed, who describes the position, topography, and geo-logical structure of the region. The rock formations are described in succession from the gneisses, schists, and Algonkian series through Cambrian and [illegible]-Devonian to Carboniferous. The geology of the region is treated in detail, commencing with the southern part of the range and [illegible] area, the [illegible] Big Baldy Moun-[illegible] Barker and [illegible] districts, and [illegible]

[illegible] the general geology and deals first with [illegible] sedimentary rocks, show-[illegible] in this region is [illegible] area of the state. The [illegible] supposed to have been the [illegible] observed in [illegible]

[illegible] the prominent mountain [illegible] whose structural features show that [illegible]

[illegible]

The concluding chapter of Mr. Weed's report contains notes on the ore deposits, under the heading: "The Ores, Veins, and Mines." The ores are chiefly those of silver, silver-lead, and gold. Sapphire mines occur in Fergus county, and are said to be the most valuable gem mines in the country. Deposits of limonite and hematite are found in a number of localities and will some day be developed economically.

The petrography of the igneous rocks by Professor Pirsson is a rather full account of the rocks, their mode of occurrence and field relations, texture, and microscopical characters, together with their chemical composition and the estimated quantitative mineral composition. It also considers the general petrology of the region, and closes with a discussion of magmas by graphic methods, and the absorption of sediments by magmas.

The rocks are subdivided into (*a*) granular non-porphyritic rocks, (*b*) acid feldspathic porphyries, (*c*) lamprophyres, (*d*) effusive rocks. In the first group are found representatives of syenites, monzonites, diorites, shonkinites, and aplites. Among the syenites is analcite-(nephelite) syenite, which, unfortunately, has not been analyzed chemically. Syenite, monzonite, and shonkinite occur together as differentiation products of one rock body at Yogo Peak. In the shonkinite the proportion between the dark and the light constituents is $\frac{65}{35}$ — that is, the former preponderate. The second group contain representatives of granite, syenite, and diorite classes, and constitute the laccoliths and many of the intruded sheets. Among these rocks there are many transitional types, the transitions being, in several cases, of much more importance locally than the more commonly-known types. Further, these transitions occur not only in different masses, but often in the same mass. The third group includes minettes, which are rather common in this district, besides nephelite-minette, vogesite, and analcite-basalts. Among the minettes is a variolitic facies, the small varioles being spherulites of feldspar. Nephelite-minette is a new variety of rock belonging to the monchiquite-alnoite series of Rosenbusch. Analcite-basalts occur as dikes in several localities. In one case the rock is estimated to contain 49.5 per cent. of analcite, the remainder being pyroxene, olivine, and magnetite. A rock closely allied to analcite-basalt carries the sapphires mined in this region. The sapphires are considered as having resulted from the absorption of fragments of clay shale included in the magma at the time of its

eruption. The fourth group includes basalt, which occurs only in two localities, as extrusive lava.

In the chapter on general petrology of the region it is pointed out that the average composition of all the igneous rocks observed would be that of a moderately acid syenite approaching an acid monzonite in character. The rocks of the larger laccoliths present a somewhat striking similarity in chemical composition and texture. They are generally phanerocrystalline porphyries. They correspond to Rosenbusch's granite porphyritic dike rocks. In this region they are pre-eminently laccolithic rocks. Their more acidic character must be taken into consideration in this connection, for in other regions less acid rocks occurring in the form of laccoliths exhibit typical granular, non-porphyritic texture. Here, as in other mountain groups of laccolithic character in the Rocky Mountain region, the depths at which the magmas are intruded appear to have exerted no perceptible influence on their granularity. It is evident that chemical composition is an important factor in the production of rock textures.

Differentiation of igneous magmas and the formation of aplitic veins are discussed and the variation in the mineral composition of the rocks at Yogo Peak is expressed diagrammatically. The application of diagrammatic methods to the discussion of chemical variations among rocks of one district is considered with special reference to Yogo Peak and the surrounding region. A comparatively simple mathematical relationship is made out for the principal rocks of the region, which is the more surprising when the intricate nature of the chemical molecules of several of the rock-making minerals is considered. It is perfectly evident, as an abstract proposition, that the chemical composition of any rock is a mathematical function of the several component minerals, whose chemical molecules are more or less variable functions of a few chemical elements. From which it may be inferred that whatever the process by which differentiation of a magma takes place the resulting solutions or magmas will probably sustain a mathematically intricate functional relation to one another. In the present instance the approximate relations appear to be comparatively simple. It is to be noted, however, that the correspondences between observed and estimated composition presented by Professor Pirsson, as he himself remarks, are merely close approximations. They are, nevertheless, striking. With regard to the absorption of sediments by magmas, the study of the igneous rocks in the Little Belt

Mountains shows that there is no evidence in this region in favor of the theory of considerable absorption.

J. P. I.

Geological Survey of Canada. Annual Report of Mineral Statistics for 1898. By E. D. Ingall, Ottawa, 1890. 196 pp.

This report shows an increase of total production for the year covered of 34.89 per cent., a production per capita of $7.32. This is compared with a total increase for the United States of 10.61 per cent., and a per capita production of $9.38, the source of the latter statistics not being given. Compared with previous years, there is a steady and large increase. From a table of proportionate values it appears that gold produces more than one-third (35.63 per cent.) of the whole, leaving coal (21.27 per cent.) well in the rear, while the next on the list are silver (6.71 per cent.) and copper (5.52 per cent.) In the preceding year coal had stood at the head of the list, the change of places being due to the large output of gold from the Yukon.

The total estimated value of metallic and non-metallic products is $38,661,000. The numerous tables usually give the production for several years previous, and afford the means for comparative studies.

C.

On the Subdivisions of the Carboniferous System in Eastern Canada, with Special Reference to the Union and Riversdale Formations of Nova Scotia, Referred to the Devonian System by Some Canadian Geologists. By H. M. Ami, Trans. N. S. Inst. Sci., Vol. X, Session 1899–1900, 17 pp.

The precise scope of the paper is well indicated in the title. The argument proceeds essentially on paleontological lines, and the physical lines of evidence are essentially set aside. In this case these latter embrace unconformities as well as the character of the rocks. The paleontologic evidence embraces plants, crustaceans, insects, mollusks, and amphibia. These are thought to indicate an Eo-Carboniferous age for the Union and Riversdale formations, which have been referred by some Canadian geologists to the Devonian system. The

author's classification of the Carboniferous of Nova Scotia is summarized in the following table:

Formations		Northern areas	Southern areas	Order
		Cape John Sandstones - -		XII
Neo-	Cape John	Picton Freestones - - -		XI
Carboniferous	Pictou	Smelt Brook shales - - -		X
	Smelt Brook	Spirorbis limestones - -		IX
	Small's Brook	N. Glasgow conglomerates -		VIII
	New Glasgow	Coal Measures - - -		VII
		Unconformity		
Meso-	Stellarton	Millstone grit	Millstone grit	VI
Carboniferous	Westville		Unconformity (?)	V
	Hopewell		Hopewell and	IV
	Windsor		Windsor	III
		Unconformity - - - -		II
Eo-	Union		Union	I
Carboniferous	Riversdale		Riversdale	

T. C. C.

Transactions of the Australasian Institute of Mining Engineers, Vol. VI. Edited by A. S. KENYON, Sec., Melbourne, 1900; pp. 247.

The following papers make up the contents:

On Safety Appliances and Precautions Necessary in Mines. By J. R. Godfrey (with 17 figures).

Contacts. By W. H. Ferguson.

Some Notes on Dry Crushing. By N. F. White (with 10 figures).

Contouring on Mining Properties with the Aid of the Tachometer. By H. P. Seale (with 10 figures).

Diamond Mines and Alluvial Deposits, South Africa. By P. R. Day.

The Manufacture of Sulphuric Acid and its Use in Metallurgy. By W. H. Mawdsley (with 10 figures).

Mine Stores. By F. Danvers Power.

The Use of Electricity in Mining. By E. F. J. Holcombe Hewlett (with 1 figure).

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[illegible] with a large number of obser- [illegible] their longer [illegible] are not coincident."

[illegible] paragraph, "[illegible]" should read [illegible]

C.

THE

JOURNAL OF GEOLOGY

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PRINCIPLES OF PALEONTOLOGIC CORRELATION.[1]

CONTENTS

General discussion.—Geologic correlation has been carried on ever since the pupils of Werner endeavored to recognize his stratigraphic divisions in remote parts of the earth; and since William Smith discovered that fossils are characteristic of certain formations, paleontologic correlation has been attempted. Still it must not be forgotten that the greater part of the correlation that has been done up to this time is based on lithologic and stratigraphic rather than on faunal data. Fossils have been regarded as incidental, useful in recognizing strata, but not as a basis for subdivisions on account of changes in fauna or flora.

Where a rock-bed of distinctive character is persistent over a wide extent of country, a lithologic correlation would reach as good, and often even better, results than could be obtained from

[1] Read before Section E. Amer. Assoc. Adv. Sci., June 28, 1900.

paleontologic data. But outcrops of strata are deceptive, and often apparently continuous beds of the same character turn out to contain a number of different formations. In the western states such lithologic and stratigraphic correlations have been, more often than not, erroneous, while in the Mississippi valley region they have usually been at least approximately correct, because the great geologic events that were the causes of the stratigraphic changes were uniform over wide areas. Even today the catastrophe doctrine of Cuvier makes itself felt, and we find paleontologists and stratigraphers using unconformities as a basis for the separation of Cretaceous from Jurassic, where the fossils do not tell a definite story, as if the uplift and erosion would necessarily come at the same time in Europe and America.

Paleontologic correlation itself is not infallible: it must be used intelligently, its sources of error known and guarded against, or else it is little more reliable than the lithologic method: these errors lie chiefly in defective knowledge of the vertical and horizontal range of species or genera chosen as criteria, and in erroneous identification of these forms. Careful collecting, accurate field and laboratory discrimination, and wide knowledge of the literature are the best safeguards.

Two sorts of paleontologic correlation may be recognized, the direct and the indirect method. In a limited province, such as existed in England and France during Cretaceous time, faunas were distributed uniformly over the area and had the same range in the two countries. Thus correlation of English and French Cretaceous strata is simple and direct, for they represent sediments that were once continuous, that were laid down in the same basins or along the same margins, under the same climatic conditions, and contained the remains of a similar fauna.

On a larger scale the problem of correlating the western European Cretaceous beds with those of the Atlantic slope Cretaceous of North America is the same. These strata were all deposited in the same faunal region, and although there are provincial differences the American and the western European faunas are remarkably similar, with even many species in common to

the two provinces, and most of the genera. During Cretaceous time there must have been easy intercommunication between Europe and America by a submerged continental shelf, keeping well within the temperate conditions. This state of things persisted through the Eocene, for the same similarity of faunas has been noted on the two continents in strata of that period.

On a still larger scale the same sort of correlation has been carried out between the western American and the Alpine Upper Trias, where many of the species and nearly all the genera are common to the two localities, although they are not in the same province, nor even in the same faunal region, and separated by six thousand miles in a direct line, and by at least twelve thousand miles by the nearest direction in which migration could have taken place. Yet there must have been easy intercommunication by continental margins from the American region, through the Oriental, to the Mediterranean region, along the borders of the ancient Mesozoic "Tethys" or central Mediterranean sea, that stretched eastward from the Alpine province through Asia Minor, India, and at least to the borders of China and Japan.

Direct correlation is possible even where there is no community of species, if a number of characteristic short-lived genera be common to the two regions. Thus the student of stratigraphic paleontology has no difficulty in correlating the *Meekoceras* beds of the Lower Trias, whether they occur in the Himalayas, Siberia, California, or Idaho; the fauna is essentially similar in all these regions, although species common to them are not yet identified. These faunas must have had a common origin either in one of these regions or in some unknown outside region, and reached the American and Asiatic provinces by migration. The place of origin may have been distant enough for the migrant faunas to have become specifically differentiated by the time they had reached their distant goals. In fact this is probably by far the more common case. Absolute specific identity between regions as distant as Asia and America must be rare; in reality there are usually in common to such regions only what

are called "representative species." This is especially true in a time of quiet development, where the fauna is largely endemic, and where there was no chance for outside elements to get into the region.

Indirect correlation also may be of two kinds; the first of these is where no fossils of extra-regional distribution are known in a formation, but where the formations above and below can be recognized. An example of this is the classification of the Algonkian system or its equivalents; the clastic pre-Cambrian, and post-Archean sediments all over the world are placed in this division, although no fauna that is characteristic is known in them as yet. Such correlation can only be tentative or preliminary, as is the present classification of the Newark formation of the Atlantic coast.

The second sort of indirect correlation is where no fossils are common to two separated regions, but elements of both are found together in a third region. A good example of this is the correlation of the Cretaceous strata of the west coast of North America with those of the interior and the Atlantic region. During the greater part of Cretaceous time the two regions were separated by a land mass so that their faunas were totally distinct, not only the species but even the genera being different. And these difficulties are seen in the attempts of the earlier stratigraphers to assign the various formations to their proper places. But when the Indian Cretaceous fauna was described, it was seen at once that there were striking analogies between that and genera and species of California. And since the Indian formation was accurately correlated with the Cretaceous of Europe, it became comparatively easy to assign the Californian strata to their proper place by this indirect comparison with the European standard. The Cretaceous of the Atlantic region had long before this been correlated with European, and thus the formations of the Atlantic region and of the Pacific coast were finally placed in harmony through the medium of comparison with a region thousands of miles from either.

Paleontologic zones.—Ever since William Smith demonstrated

that the various beds of the English Jurassic may be recognized by their fossils, the stratigraphy and paleontology of this formation have been a favorite field for investigation. Jurassic strata with abundant marine fossils are widely distributed in England, France, Germany, and Switzerland, in easy reach of universities and museums, so that the student of these faunas has an unusual wealth of material at hand. And in this western European province comparatively uniform conditions prevailed during the greater part of this time, allowing the faunas to become widely distributed. It is doubtful if any other succession of fossil faunas in the world is so well known as that of the Jurassic of this province, or if anywhere else such minute stratigraphic and faunal division has been successfully carried out; for there is not a single bed in all the great thickness of Jurassic sediments that does not contain somewhere in this province a rich marine fauna.

Quenstedt devoted his life to a minute subdivision of the Jurassic of Württemberg, establishing a classification that still holds sway in Germany; but this classification was based on local faunas, whose appearance and disappearance were caused by insignificant local changes in sedimentation, and it could hardly be used away from the place where it originated. In this scheme the greater unconformities, overlaps, and faunal changes received no more attention than the smaller geologic events. It was, then, merely a useful local classification, although of great value as a starting point in comparative study.

It was reserved for Albert Oppel,[1] a pupil of Quenstedt, to establish a chronological classification, based entirely on paleontology, and independent of lithologic development. For the entire Jurassic formation Oppel recognized thirty-three zones, or subdivisions characterized by certain species that occurred only in these horizons. The species chosen were of the greatest horizontal and the least vertical distribution, and were usually ammonites. These zones were thought by Oppel to be universal, for he was able to recognize them in Germany, Switzerland,

[1] Die Jura Formation, 1856.

France, and England, and by means of them was able to bring into harmony the local subdivisions already established in these various countries.

This was an important step in the right direction, but experience has shown, since Oppel's time, that these zones were not universal, and could seldom be recognized outside of the province where they were established — not even there always, when there was much difference of facies. So this scheme failed of its immediate purpose, although the final results of it have been more important than Oppel probably ever anticipated.

A further application and enlargement of Oppel's plan has been attempted by Buckman,[1] who has divided the Jurassic formation into *hemerae*, based on the occurrence of certain characteristic species of ammonites. An *hemera* represents a time considerably shorter than a zone, for the Lias, or Lower Jura, alone is divided into twenty-six *hemerae*. These are undoubtedly of much use to the stratigraphic paleontologist in England, probably in France, and possibly in Germany; but these *hemerae* can not possibly be identified away from the limited province where they were established, for in the Alpine or the Austrian Jura one is often lucky to be able to tell whether certain beds belong to Lower, Middle, or Upper Jura. Such finely drawn subdivision is of use only in local stratigraphy.

Buckman further classed a number of *hemerae* together in *ages*, based on the development of a group or series of species; in the Lias alone there are four of these *ages*, which correspond more nearly to the zones of Oppel, but even these could hardly be recognized in southern Europe, and much less in Asia or America.

Oppel thought that his zones were universal, or interregional, but only occasionally can one of them be identified outside of the province where it was named. This is due to the distribution of certain characteristic fossils outside of their usual range, on account of conditions temporarily facilitating interregional

[1] Quart. Jour. Geol. Soc. London. Vol. LIV, 1898. On the Grouping of some Divisions of so-called Jurassic Time.

migrations, which can occur only at times of readjustment of faunal provinces. There can be none in the intermediate periods of stability and quiescence when the fauna is endemic.

The writer proposes to retain the term "zone," in the sense intended by Oppel, as a chronologic term for a limited horizon, or time division, characterized by an interregional fauna. Use of the term in this significance would recognize not only biologic development, but also geologic events, for an interregional fauna can appear only in times of readjustment of biologic regions, of trangressions of the sea on the land, or of opening up connections between regions that before were separated. These are nature's periodic trial balances, during which the geologic columns in various regions, for a while divergent in biologic development and thus in stratigraphic classification, are brought into harmony.

A zone, in this sense, means a comparatively short time in which a certain characteristic, limited group of animals or plants lived—too short for any great faunal change, but long enough for this group to diffuse itself over a great area. To illustrate this let us take a well known example. It must have taken a long time for *Productus semireticulatus* to be dispersed through the seas of Australia, Eurasia, and America, for it is found in all those regions. But no stratigrapher would choose this species as a zone fossil, since it ranges from the Mountain Limestone into the Permian; often characteristic of a certain province during a given time, but of no one horizon everywhere. And during this long time the greater part of the accompanying faunas underwent enormous changes, until most of the genera, even, were new. During all these migrations *Productus semireticulatus* itself underwent modifications until it might be divided into a number of geographic species or varieties, and each of these into mutations or varieties in an upward-ranging genetic series. But accompanying *Productus semireticulatus* there are many species and genera that were short-lived and widely distributed, in some one region appearing as a link in a genetic series, but in some other region appearing sporadically or unheralded by local ancestors, and brought in by immigration

from the outside world. The appearance of such genera or species is an interregional event, and marks an episode in the dynamic history of the earth. Zones are thus not a figment of the stratigrapher's imagination, but are based on geologic events of far-reaching importance, in comparison with which the local shiftings of lithologic facies are insignificant.

Ancient faunal geography.—One of the first things that attracted the attention of naturalists engaged in the study of geographic zoölogy was that animals are not now distributed strictly according to climate, or other physical conditions. Edward Forbes early reached the conclusion that the ancient marine faunal provinces and regions by no means corresponded with the present distribution, and that the present faunal relations could be explained only by study of past geologic changes in the distribution of land and water. The various marine provinces were grouped by S. P Woodward[1] in great regions: "The tropical and subtropical provinces might naturally be grouped in three principal divisions, viz., the Atlantic, the Indo-Pacific, and the West-American—divisions which are bounded by meridians of longitude, not parallels of latitude. The Arctic province is comparatively small and exceptional; and the three most southern faunas of America, Africa, and Australia differ extremly, but not on account of climate."

What is true of faunal geography today was true of it in the past. While certain faunas, such as the Silurian, have been very widely distributed, on account of the existence then of wide expanses of shallow marginal and epicontinental seas, there were no such things as universal faunas, even in the most remote geologic time. There have always been barriers of continent and ocean, and probably too of climate, ever since life existed on the earth. Only the deep sea faunas could be universal if oceanic basins had been stable; but such faunas are not universal now, nor have they remained unchanged in time.

Many years ago Barrande[2] showed that the Cambrian

[1] Manual of the Mollusca, 1850, p. 353.

[2] Système Silurien du Centre de la Bohème.

deposits known at that time could be grouped in well-defined geographic provinces; it is true that there was a great similarity of animal life in the various regions, but this by no means amounted to identity. Most genera had a wider range then than in later formations, but community of species was as rare in the Cambrian as in the later Mesozoic. Walcott has divided the Cambrian into three great divisions, each named after the most characteristic genus in it: the lower, or *Olenellus* zone; the middle, or *Paradoxides* zone; and the upper, or *Olenus* zone. No one of these had a universal fauna, although certain subdivisions can be traced through several provinces and even regions, and thus deserve the designation "zone," as Oppel used the word. It is noteworthy, too, that these times of interregional distribution come at periods of transgression of the seas on the land, so that a connection between these two phenomena may justly be inferred.

The work of Barrande, James Hall, and Murchison has shown that the Silurian strata and their fossils are as widely distributed as the Cambrian. But during Lower Silurian time the faunas of the American and the European region seem to have been largely endemic. The Trenton sea probably covered the greater part of North America, but only that in the northeastern part of the region shows much relationship to the European. During the Upper Silurian there was considerable readjustment and shrinkage of the sea, and as a consequence of this the Niagara limestone may justly be considered as an interregional zone, although the exact period of the migration cannot be determined.

During the Lower and Middle Devonian the division into regions that had existed in the Silurian still held sway, for it has been shown by H. S. Williams that there was a North-South American and a Eurasian region. But with the beginning of the Upper Devonian the connections had changed so that the grouping was Eurasian-North American, and South American-South African. This change shows itself in North America at the base of the Upper Devonian, where with the *Cuboides* zone

was a time of encroachment of the land on the sea, and only occasionally, when the sea had temporarily reclaimed its own, are marine faunas found in this formation. But when these occur, they are often extra-provincial, and occasionally extra-regional in origin, and thus give a secure basis for correlation with those regions where marine conditions still prevailed. Such a state of affairs existed in western North America and in eastern Europe during the time of the Coal Measures; in these regions the sea transgressed over the land areas, and allowed the marine faunas to become widely distributed. By intermittent subsidence of the low-lying coal swamps an intercalation of marine with freshwater deposits took place, allowing accurate correlation between the two facies.[1] And occasionally these oscillations have been something more than local events, for they have brought in exotic faunas, as in the case of the belated immigration of *Pronorites cyclolobus* and *Conocardium aliforme* in the Lower Coal Measures of America, or the appearance of *Gastrioceras* and *Paralegoceras* in the European waters long after they had appeared in America. The greatest of these disturbances was the Appalachian revolution, which at the beginning of Permian time raised finally above water the continental borders of the old Appalachian land mass, and left only a comparatively small basin for the Permian sea. This rising of the Mississippi valley region was undoubtedly accompanied by sinking elsewhere, for a very similar exotic fauna appeared simultaneously in the American, the European, and the Asiatic region, and mingled with the preëxisting local faunas, giving one of the most distinctive paleontologic zones yet known,

During the Lower Trias the Arctic, the American, and the Oriental regions had closely allied faunas, and might be grouped together in contrast with the Mediterranean. At this time of transgression and readjustment of geographic boundaries we have the widely distributed fauna of the *Meekoceras* zone, distinctly recognizable in India, Siberia, and western America.

[1] J. P. SMITH: JOUR. GEOL., Vol. II, No. 6, 1894, The Metamorphic Series of Shasta County, California.

The Middle Triassic faunas seem to have been largely endemic, because the waters of that time were stable; thus there are no horizons that are directly comparable in distant lands. But again the Upper Trias ushered in a period of transgression and invasion, and the faunal zone of *Tropites subbullatus* appeared simultaneously in the Mediterranean region, in the Himalayas, and in California, with many genera and species common to these countries, exotic in all, and with no previous record to show their origin.

The geographic provinces of Jurassic time have been grouped by Neumayr[1] in two great regions, the Boreal and the Central Mediterranean, and further he has traced out the distribution of climatic zones of that time in the Boreal type, the North Temperate type, the Alpine or Equatorial, and the South Temperate. The western American province belonged to the Central-Mediterranean region and to the North Temperate climatic zone during Lower and Middle Jura, but with the beginning of the Upper Jurassic a great change took place in physical and faunal geography that connected the western American province for a time with the Boreal region. As a consequence of this the faunal zone of *Cardioceras alternans* and *Aucella pallasi* may be traced through Russia, Alaska, and California.[2] The disturbance that caused this invasion may easily be traced in the transgression eastward of the sea on the land that began in northern Europe already in Middle Jurassic, bringing down from the northwest a cold current that permitted the Boreal fauna to make its way into temperate latitudes on the western coast of North America.

The study of the distribution of fossil faunas as influenced by climate was begun by Ferdinand Roemer,[3] who recognized the fact that the Cretaceous of western Europe was similar to that of the Atlantic region in America, and that the faunas of southern Europe, northern Africa, Texas, and Mexico had much in

[1] Denkschr. K. Akad. Wiss. Wien, 1883, Klimatische Zonen während Jura und Kreidezeit.

[2] J. P. Smith: Jour. Geol., Vol. III, 1895, Mesozoic Changes in the Faunal Geography of California.

[3] Kreidebildungen von Texas, 1852.

common. These differences Roemer ascribed to climate, noting that then, as now, the isothermal lines came much further south in eastern America than in Europe.

It has been shown that at the beginning of Cretaceous time the faunal relations of the west coast of North America were still with the Boreal region, as in the Upper Jurassic. But this did not last long, for even before the end of the Knoxville epoch this fauna had died out, and was replaced by immigrants from another region. At first there were only a few stragglers, but soon the rich fauna of the Horsetown stage or Gault made its appearance, of a type precisely like that of southern India, and eastern Africa. A similar association of genera and species is also known in the European region, where it seems to have been endemic, and from which it probably reached the rest of the world by migration. This incursion of exotic faunas marks the last great period of readjustment of the geologic column in various parts of the world, and is therefore of the utmost importance in correlation. The kinship of the western American faunas to the Indian was stronger than that to the eastern American almost until the end of the Cretaceous, when a similarity to the interior province began to show itself. This change culminated in Eocene time, in the zone of *Venericardia planicosta*, when the barrier between the western and the interior Cretaceous provinces was temporarily removed, and through the Atlantic there was direct connection with the European waters. This is the last interregional zone, but it marked an era of retrogression of the sea, rather than of transgression, and since that time the marine provinces and regions correspond closely with the existing boundaries of temperature and shore lines.

Dispersion of marine animals in past and present.— Theoretically, pelagic faunas would be the best means of correlating distant regions; but in all probability we have no fossil pelagic faunas. J. Walther suggests that in the widely dispersed species of Mesozoic ammonites we have virtually a preservation of pelagic animals, or at least that their shells floated after death, and were distributed all over the earth by marine currents. This

sounds plausible, viewed in the light of what we know of the distribution of *Spirula*. But the living Pearly Nautilus is not distributed by currents away from the region of its present habitat, and in studying fossil faunas we find that the cephalopods had little wider distribution than brachiopods and pelecypods, animals usually fixed in station during most of their life, and able to migrate only during the larval stage. Another argument against the current-distribution hypothesis has been brought up by Dr. A. Tornquist, that the fossil ammonites of Jurassic and Cretaceous age are distributed approximately according to climatic zones.

The geologic record has been kept by the inhabitants of submerged continental or island shelves, and their dispersion cannot have been accidental or individual, but was faunal. The means and the reason for this migration are furnished by changes in physical geography. Any rising or sinking of shore lines would drive the inhabitants from their dwelling places; any newly opened connections between regions that before were separated would cause an intermingling of different faunas. An example of this is going on before our eyes today; the Red Sea and the Mediterranean have faunas as distinct as if they occurred on opposite sides of the world, but since the opening of the Suez Canal, intermigration has already begun, and in this present age will be recorded an inter-regional invasion comparable with those that took place in remote geologic time. And no doubt to some future geologist this record will be just as clear as those we have of similar changes in the past. Each great change in the outlines of continents must also have caused great changes in the direction of marine currents. Thus in the great subsidence of land in northern Eurasia that caused the transgression of the Upper Jurrasic sea must have opened the way for the cold current that came from the northwest along the Pacific shore of North America, bringing a Boreal fauna into temperate latitudes. Something similar to this would happen if, at some future time, the old dismembered Antillean continent were raised to its former position; the Gulf Stream could not enter the warm waters

of the Carribean, would be deflected, and the waters of the northwestern coast of Europe would be chilled.

The horizons of America that represent periods of instability of shore lines are the very ones that contain the remains of exotic faunas, such as those of the *Cuboides* zone, the *Intumescens* zone, the Chouteau limestone, the St. Louis beds, or the shifting zones of the Coal Measures. These migrations must all have been faunal rather than individual, and can have been due only to physical agencies acting slowly and on a large scale. No extraordinary catastrophies need be appealed to as an explanation of this, for similar phenomena are always going on before our eyes, in the slow but ceaseless rising of some shores and sinking of others.

Land masses present an insuperable barrier to marine animals; but if the bodies of land are short, and do not reach into polar waters, animals can easily pass around the ends. Thus the molluscan fauna of the Mediterranean does not differ greatly from that of the English waters, because in the passage around the peninsula of Spain, animals remain in temperate waters and under nearly the same conditions. East and west land masses would, therefore, not be effectual barriers, since they would not be so likely to extend into frigid waters nor into very great differences of temperature. An example of this is the similarity of marine faunas on the east and the west coast of Australia.

On the other hand, the Isthmus of Panama separates two faunas absolutely distinct from each other, although in the same latitude, and under the same climatic conditions. Also the Isthmus of Suez separates two totally distinct faunas, but these belong to different regions and even to different climatic zones, brought near together by the narrow strip of the Red Sea. A similar case is known in the Jurassic formation, where the fauna of western Europe stands sharply contrasted with that of Russia; even the characteristic genera are distinct, and this too in latitudes not very different. These two types represent two seas of different climatic zones, separated by a strip of land during the later portion of Jurassic time.

That climatic zones alone are to-day partial barriers to migrants along the coast is shown by the difference in faunas living in northern and in southern latitudes on north-south shores. We would expect cold water species to be able to cross climatic zones more easily than those adapted to warm water. But we know of no cases where equatorial faunas have passed through arctic regions, and even passages from tropical into temperate waters must have been exceedingly difficult, for a fall of a few degrees below the temperature favorable to life must be a great deal more destructive than a rise of many degrees. At present we have no means of testing this statement, but facts brought to light by geology confirm it. The Jura of western Europe and of the Argentine Republic have practically the same fauna, which, in reaching one of these regions from the other, must have passed from temperate waters through tropical, and into temperate seas again. The genera *Lytoceras* and *Phylloceras* are common in the Neocomian beds of southern Europe; but although these waters were undoubtedly connected with those of northern Europe, those genera are lacking in the latter region. Also in the lower part of the Californian Knoxville beds, the above mentioned genera are unknown, and come in only higher up where the first members of the tropical Indian fauna began to appear.

By far the greater part of marine animals live near the shore and are unable to exist under other conditions. To these an abyssal sea is as impassable a barrier as a continent. The marine faunas of the southern ends of Africa, South America, and Australia are in approximately the same climatic conditions, but although they are connected by open seas, they are as different as if they were in totally disconnected basins. But an east-west sea affords good opportunity for passage from one side to the other by slow passage along the margin. The present fauna of the Mediterranean is good evidence of this, the animals of the European shores not differing appreciably from those of the African. The Mesozoic faunas of the ancient Central-Mediterranean sea owe their great distribution to this fact, for nearly the

same conditions existed then as in the present Mediterranean, except that the extent was vastly greater.

And even on opposite sides of great north and south oceans there are usually many species in common; the Atlantic shore American fauna has many European species, and the Pacific shore harbors some from Asiatic waters. Their passage was affected in most cases along continental borders that have since been obliterated by subsidence and erosion. We have an abundance of geologic and biologic evidence that just such changes have taken place in comparatively recent time, for example, the dismemberment of the old Antillean continent since Tertiary time. Also in the Indian Ocean there existed a continent in late Paleozoic and early Mesozoic time, connecting Australia with Asia; and Wallace[1] has shown that even since the Tertiary, Australia has been connected with many of the now separated islands of the Indian Ocean, although cut off even then from Asia.

The occurrence of identical or very closely related species in widely separated localities is good evidence of migration from one of these localities to the other, or from a third region to both. In many cases faunas even appear unheralded by local ancestors; these are exotic, having been brought in by migration from outside regions. In the chapter on paleontologic zones many of these exotic faunas have been enumerated, and the general statement made that their appearance invariably coincides with a time of shifting of the boundaries of land and sea, and consequent opening of new connections.

Colonies.— It is often noticed that species or faunas are intermittent in occurrence, especially when the character of the sediments is shifting. When sands are being deposited in shallow waters certain animals find their favorite habitat there, and when subsidence cuts off the clastic sediments and the waters become clear, other animals hold sway. Such faunal changes are due to the facies of sedimentation, but both sorts lived in the same

[1] Geographical Distribution of Animals, Vol. II, The Australian Region, pp. 387–485.

province and near together. But intermittence of occurrence is occasionally noted when it cannot be due to difference of facies. Just such a case is the reappearance of a Chouteau fauna in the Osage horizon of Missouri,[1] or the reappearance of Devonian types in the St. Louis beds at a number of places in the United States. In the Jura of northern Europe, according to Neumayr,[2] the genera *Lytoceras* and *Phylloceras* appear only sporadically, being lacking in sixteen zones; and even the known species there do not belong to a genetic series. But in southern Europe these genera appear plentifully in all the zones, and seem to represent genetic series. Their migration northward at several successive periods is thus clearly established. In these same beds *Amaltheus* also appears intermittently, but no region is yet known where *Amaltheus* developed continuously. Among the Jurassic ammonites of northern Europe there are a number of other cryptogenic types, many of which coincide with the *Amaltheidae* in their appearance, and thus probably came from the same region.

Today, when the struggle for existence becomes too severe for a species it disappears. In geologic history, too, a species has a certain length of life and dies out, never to reappear. This has given rise to the theory that species, like individuals, have a limited life, and that in time they reach a stage of development where they can go no further, and then of necessity die out. This would all be very well if species dropped out one at a time and contemporaneously all over the earth, but in reality they come and go by faunas. A study of the successive fossil faunas of the Pacific coast region has shown that while there may be a nearly perfect stratigraphic series, the faunal succession is broken, so that each fauna appears unheralded, in a way that would have delighted the heart of Cuvier. But we often find the forerunners of these unheralded faunas in older beds in other regions; this gives the rational explanation of the phenomenon,

[1] C. R. KEYS: Amer. Jour. Sci., Dec. 1892, p. 447.

[2] Jahrbuch K. K. Geol. Reichsanstalt, Wien. Bd. 28, 1878. Ueber unvermittelt auftretende Cephalopodentypen in Jura Mittel-Europas.

migration due to the removal of barriers.[1] It would seem, then, that changes in physical geography have been the chief cause, not only of migration, but also of extinction of faunas; and this becomes all the more probable when we reflect that species have not been extinguished contemporaneously over the earth.

Remarkable cases of survivals of types have long been known, as of *Trigonia* in the Australian waters, and of *Pholadomya* in the Antilles. Survivals of faunas, too, are continually coming to light. A number of species that on the west coast of the United States are known only as fossils in Pliocene and Quaternary strata, are still living elsewhere. Dall[2] has shown that a large proportion of the Pliocene and even Miocene invertebrates of the southeastern states are still found living in the archibenthal region off the present coast. Similarly, it has been shown by Walcott[3] that in the Great Basin Carboniferous province many Devonian types persisted long after they had become extinct elsewhere, and this has been used by H. S. Williams[4] to explain the reappearance in the Mississippi valley St. Louis beds of a fauna previously thought to have been extinct since the very beginning of Carboniferous times.

Dr. David Brauns[5] cites from the late Pliocene or early Pleistocene of Japan a large number of species that are still flourishing on the western coast of America, and some are found living there that in western America are known only as fossils. Thus in the future some confusion might originate by correlating these beds with those now forming.

It is well known that during the Upper Carboniferous there flourished in India, South Africa, and Australia the *Glossopteris* flora, a type that in other regions was characteristic of Mesozoic instead of Paleozoic beds. Waagen[6] has suggested that the

[1] J. P. SMITH: JOUR. GEOL. Vol. III, 1895. Mesozoic Changes in the Faunal Geography of California.

[2] Bull. Mus. Comp. Zoöl., Vol. XII, No. 6, p. 186.

[3] Mon. VIII, U. S. Geol. Survey.

[4] Amer. Jour. Sci. III Ser., Vol. XLIX, pp. 94–101.

[5] Mem. Science Dept. Univ. of Tokio, No. 4, 1881, p. 77.

[6] Pal. Indica. Salt Range Fossils. Geological Results, p. 240.

glaciation in this region near the beginning of Permian time killed off the Paleozoic flora and allowed the *Glossopteris* flora to get a foothold earlier than was the case where there was no glaciation. Such phenomena approach the nature of catastrophes, and show that Cuvier's doctrine was not altogether wrong after all, and he probably had something like this in mind, although not formulated. These facts, too, show that the principles on which Barrande's[1] doctrine of "colonies" was founded were right, even though it has since been found that the particular cases on which he based his colonies were only younger rocks carried into the midst of older beds by dislocations. Barrande's idea seems to have been that in certain separated basins a new type of life would be introduced before it appeared elsewhere, and that by changes in physical geography these precursor faunas would be intercalated with those of older type. The modern doctrine of colonies, on the other hand, is that older faunas have often been preserved in places where no great changes have taken place in the conditions necessary for their life, and that these older surviving faunas have been mingled as anachronisms with the younger through immigration made possible by the removal of barriers, or changes in the direction of ocean currents.

Synchronism vs. homotaxis.—Forms are said to be heterochronous when they occur at different horizons, in different regions. Now it is possible that the same species seldom occurs at exactly the same time in two widely separated places; it must originate at the one and migrate toward the other, or migrate to both from a third place. This would take time, and it is supposable that the species might be entirely extinct at the point of origin before it reaches its second habitat, or become so greatly modified on its journey as to require a new name, or a number of new names. A case in point is the migration and development of *Ceratites nodosus* in the middle Trias of Germany. In the North-German basin this species is exceedingly common in the Muschelkalk, and exceedingly variable, but the boldest species-maker has not yet dared

[1] Système Silur. du Centre de la Bohême, Vol. I, p. 73 et seq.

to split it up into a number of species, because there are transitions between all the varieties. Dr. A. Tornquist[1] has recently shown that *Ceratites nodosus* also occurs in the upper Muschelkalk of the southern Alps, and that there the varieties lack the transitions, and thus may be given names to mark this transformation. The immediate varieties never reached the Alpine province, or else the modification took place on the way. The zone of *Ceratites nodosus* is thus inter-provincial in extent.

A somewhat similar case is known in the distribution of certain living species of the genus *Purpura;* in the English waters *Purpura lapillus* is common and exceedingly variable, but no constancy can be traced in these variations, the influence of temperature, sea bottom, and food supply being so evident, and the transitions so gradual that no subdivision of the species is attempted. Some of these same varieties are found on the western coast of America, but without the transitions, and so they are called by a number of specific names, which, although they are given to forms locally distinct, can certainly be only synonyms of *Purpura lapillus.* At some not very distant time these forms migrated westward from the Atlantic waters, and either varied on the journey, or else the intermediate forms did not succeed in reaching the Pacific region.[2] Here is certainly an interregional migration where a species is still living in the waters where it originated.

The genus *Clymenia*, according to J. M. Clarke,[3] appears in the *Goniatites intumescens* zone in New York ; in Europe *Clymenia* is wholly unknown in the *Intumescens* fauna, but is the characteristic form of the next higher division of the Devonian, where the *Intumescens* fauna was already extinct. In North America *Pronorites cyclolobus* and *Conocardium aliforme* appear in the Lower Coal Measures, while they flourished in Europe in the zone of

[1] Zeitschrift d. Deutschen Geol. Gesell. Bd L. Heft 2, 1898, and Heft 4. 1898. Neuere Beiträge zur Geol. und Paläntol. der Umgebung von Recoaro and Schio (im Vicentin).

[2] A. H. Cooke, Mollusks, 1895, pp. 90 and 363.

[3] Am. Jour. Sci., Ser. 3, Vol. XLIII, p. 57.

Goniatites striatus of the Mountain Limestone. The genera *Gastrioceras* and *Paralegoceras* appeared in America in the zone of *Goniatites striatus*, while they are not known in Europe before the Coal Measures. But the accompanying faunas in these regions are, in the main, correlative, and so the heterochronous appearance can be detected.

In the Upper Trias, Karnic stage, of California *Halorites* occurs, although in both the Alps and the Himalayas it is characteristic of the higher Noric stage. Also in California *Trachyceras* and *Protrachyceras* occur in the zone of *Tropites subbullatus*, mingled in the same hand specimen with typical species of the *Subbullatus* fauna; in the Alps and in the Himalayas *Trachyceras* and *Protrachyceras* are older than the *Subbullatus* zone, and are never found in it.

Now, when we have fossil species or short lived genera common to two regions, are the strata of these regions to be considered as synchronous? Huxley[1] advanced the theory that migration from one region to another would consume so much time that a fauna might become extinct in one region before it reached the other, and that since we determine the age by these faunas, the time of deposition of strata assigned to the same geologic age might be very different. Thus a Silurian fauna might survive in one region, while a Devonian fauna flourished in a second, and a Carboniferous fauna might be beginning in a third region. But the fossiliferous beds are Silurian, or Devonian, or Carboniferous in the faunal sense. This relation Huxley called *homotaxy*, and most geologists have accepted without question the validity of the hypothesis.

Viewed in the light of modern distribution of fauna, there must be something in it. The present Australian fauna is often cited as an example of unreliability of the time scale when based on faunas, as a survival of Quaternary life at the present time; it certainly is peculiar, for the continent has been totally cut off from other regions since early Mesozoic time. This fauna, however, has not dropped behind; it has gone on specializing in

[1] Presidential address. Quart. Jour. Geol. Soc. London, 1862. Vol. XVIII.

TABLE OF INTERREGIONAL ZONES

		EUROPE	NORTH AMERICA	ASIA
TERTIARY	Pliocene			
	Miocene			
	Eocene	Zone of Venericardia planicosta	Atlantic States, Gulf Region, California & Oregon	
CRETACEOUS	Upper	Zone of Hippurites	Texas & Mexico	
		Zone of Schloenbachia	West coast & Interior	India
	Lower	Zone of Acanthoceras mamillare	West Coast	India
		Zone of Aucella terebratuloides	California & Alaska	Siberia
JURASSIC	Upper	Zone of Cardioceras alternans	California	India & Siberia
	Middle			
	Lower	Zone of Arietites	Nevada & California	[illegible] & Island of Rotti [illegible]
TRIASSIC	Upper	Zone of Tropites subbullatus	California	India
	Middle	Zone of Ceratites & Beyrichites	Nevada	India & Siberia
	Lower		Zone of Meekoceras fauna in California & Idaho	Siberia & India
CARBONIFEROUS	Permian	Zone of Medlicottia in Sicily & Russia	Texas	India & China
	Pennsylvanian	Zone of Gastrioceras marianum	Mississippi Valley & Texas	? Beds of Lo Ping China
		Zone of Gastrioceras listeri	Mississippi Valley	
	Coal Measures	Zone of Glyphioceras [illegible]	Arctic America	Sumatra ?
	Lower Carboniferous	Zone of Goniatites striatus	Mississippi Valley & Texas	
		Zone of Productus giganteus in Russia & Belgium	California	Siberia & China
		Zone of Glyphioceras [illegible]	Mississippi Valley	
DEVONIAN	Upper	Zone of Manticoceras intumescens	New York	Siberia ?
		Zone of Rhynchonella cuboides	New York	Siberia
	Middle			
	Lower			
SILURIAN	Upper	Zone of Calymmene blumenbachii	Mississippi Valley & New York	
	Lower			
CAMBRIAN	Olenidian	Olenus fauna	Canada	
	Paradoxidian	Paradoxides fauna	United States & Canada	
	Olenellian	Olenellus fauna	United States & Canada	

its own lines, and in all the geologic ages to come will never reach the development of life as we know it elsewhere in the Era of Man.

But is the marine fauna on the Australian shores markedly different from that in other parts of the Indian Ocean, and has that of the Indian Ocean no near relationships with the outside world? There are faunal provinces in these, with local characteristics, but with gradual transition from one province to another, and from one region to another through adjacent provinces. Thus the Australian waters show a gradual transition in fauna to the China Sea, and that to the Japanese marginal fauna, which, in turn, show many species in common with the west American region.

If, then, the modern Pacific and Indian Ocean marginal faunas were fossilized it would be no great task to correlate them, although the western coast of America might not show a single species in common with Australia. The laws that govern the distribution and intergradation of marine faunas are the same now as they have always been. All stratigraphic classification and all paleontologic correlation are based ultimately on fossil marine faunas.

The reality of correlation.—The geologic succession of faunas has some irregularities and anomalies, as shown above, but the displacements of the time scale are too slight and the uniformity in various separated regions too great to lay much stress on homotaxis as opposed to synchronism. While homotaxial strata are not necessarily synchronous in years nor in centuries, the cases cited above show that they often are actually contemporaneous. But even if they were not, years and centuries count little as compared with the time back to the Quaternary, and still less with the great stretches of time in the Paleozoic. And if a Silurian fauna still persists beyond its time by reason of local favoring conditions, it is merely a transient exception, for interregional migration soon readjusts the faunal scale in harmony with the time scale. The survivals of species or faunas are the exception rather than the rule, and such anachronisms can be detected in the past as well as now.

If there had ever been any great displacement of the faunal scale from the time scale, this would have been cumulative, and eventually the paleontologic column of America would have been out of harmony with that of Europe. But the successive faunas from Lower Cambrian to Pleistocene are in perfect accord in all the regions of Europe, Asia, Africa, America, and Australia; there are constantly recurring small displacements due to temporary isolation, and constantly recurring readjustment due to reopened or newly-formed connections, giving interregional correlative faunal zones through migration. These zones may be, and often are, actually synchronous. The periods of endemic development may be homotaxial, but the zones of readjustment are correlative in the strictest sense.

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CONTRIBUTIONS FROM WALKER MUSEUM. I.

THE VERTEBRATES FROM THE PERMIAN BONE BED OF VERMILION COUNTY, ILLINOIS.

THE material described and figured in the present contribution comprises a portion of the vertebrate material of the Gurley Collection of Fossils in the Walker Museum, at the University of Chicago. The material is of extreme interest from both an historical and a scientific standpoint, its discovery being the first evidence of the occurrence of Permian reptiles in North America. A few isolated bones were submitted to Professor Cope, and with his usual keen insight he recognized their character and their value, and by his interest he stimulated the work of their careful collection and preservation. To Mr. Gurley is due the credit for a careful and exhaustive exploration of the "bone bed," and the preservation of the material.

Many of the forms were described by Cope in the files of the Proceedings of the Philadelphia Academy of Natural Science, and the American Philosophical Society, but only a few illustrations of the intercentra of *Cricotus* have ever been published. It was his intention to publish full descriptions of the forms, with illustrations, and for this purpose plates had been prepared for an article in one of the government publications, which was never issued. Much of the material is fragmentary, and nearly all the bones were found isolated, so that it is especially difficult to identify the species from the descriptions alone. Especially is this true when the specimens to be compared come from another locality.

In the present paper the original descriptions have been reproduced, wherever they would serve the purpose, along with some additional notes, and the specimens figured. In many instances the figures have been copied from those prepared by Cope for his unpublished work. A few of the specimens

described by Cope are now missing from the collection, and so cannot be figured.

Several specimens are preserved in the collection which were never described by Cope. I have refrained from giving new names to these, as it is altogether probable that the seemingly new forms are but portions of the skeleton of animals that have been named from other parts of the skeleton. The numbers given at the close of each description, are the record numbers of the Paleontological collection in Walker Museum, at the University of Chicago.

Janassa strigilina Cope. Plate I, Figs. *1a*, *1b*, *1c*.

Strigilina linguæformis Cope, 1877, Proc. Am. Phil. Soc., p. 53. (Specific name preoccupied in 1868 by Atthey.)

Janassa strigilina Cope, 1881, Am. Nat., p. 163.

Janassa strigilina Woodward, 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 38.

Generic characters: "The tooth is a flat, osseous plate, whose outline is pyriform, the wider end recurved in one direction as the transverse cutting edge; the other extremity narrowed and recurved in the opposite direction as the root. The side from which the cutting edge arises is crossed by numerous plicæ from the base of the root to near the base of the cutting edge; the opposite side is smooth."

Specific characters: "The plicate surface terminates behind in a median angle, at the base of the root. There are eight plicæ which all cross the plane, excepting the sixth, which is interrupted in the middle by the strong angulation of the seventh, which touches the fifth. The lateral extremities of the right are in contact with the base of the recurved cutting portion. The latter is convex transversely, leaving a smooth surface between it and the eighth plica. The smooth side of the tooth is shining, and there is a shallow fold, which passes around its side and crosses just at the base of the recurved cutting lamina."

MEASUREMENTS.

"Total length of the plane - - - - -	.008 m
Width at base of the cutting lamina - -	.006
Width at the base of the root - - - -	.004
Thickness of plane portion - - - -	.0015 "

[No. 6500.]

Janassa gurleyana Cope. Plate I, Figs. *2a*, *2b*, *2c*.

Strigilina gurleiana Cope, 1877, Proc. Am. Phil. Soc., p. 191. (Pal. Bull., No. 26.)

Janassa gurleiana Cope, 1881, Am. Nat., p. 163.

Janassa gurleiana Woodward, 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 39.

"The tooth is quite small, its length only equaling the width of the known tooth of *S.* (*Janassa*) *linguæformis*. It is also narrower in proportion to the length. The root and the cutting edge are turned in opposite directions as in the other species. The principal difference between the two is seen in the character of the transverse ridges or crests of the oval face. There are two crests less, or five, with a delicate basal fold, making six, while, counting the fold, there are eight in *S.* (*Janassa*) *linguæformis*. The anterior ridge is transverse; the others slightly convex backwards, and all are equidistant and uninterrupted, which is not the case in the older species. They are also of different form, being distinct ridges with anterior and posterior faces similar. In *S.* (*Janassa*) *linguæformis* the anterior face only is vertical, the posterior descending very gradually, the whole forming a series of steps.

"Length of the ridged face, $.0060^{m}$; width anteriorly, $.0035^{m}$; width posteriorly, $.0020^{m}$."

[No. 6501.]

Pleuracanthus (**Orthacanthus**) **quadriseriatus** Cope. Plate I, Figs. *3a*, *3b*.

Orthacanthus quadriseriatus Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

Pleuracanthus quadriseriatus Woodward, 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 9.

Represented in the collection by imperfect radial spines. Both Newberry and Cope remark that it is very likely that the spines called *Orthacanthus* may belong to the the same fish as the teeth called *Didymodus* (*Diplodus*), and as the teeth are distinctly referable to the genus *Pleuracanthus Ag.*, it is perhaps best to follow Zittel in regarding all three names as synonyms of *Pleuracanthus*. The teeth and spines are found in close connection. The species here described differs from the *O. gracilis* of Newberry in having the denticles shorter. The description given by Cope is as follows: "The spine is wider than deep, and the series of denticles are widely separated. The surface between them is gently convex and smooth. The anterior face is strongly convex, and presents at each side two shallow furrows. The external groove is divided by a series of thin longitudinal denticles which are smaller than those of the principal row, and which are

sometimes confluent at the base. The principal denticles are closely placed, stout, acute, and recurved.

"Transverse diameter of shaft .0035^{m}; antero-posterior diameter .0025^{m}; the portion of the shaft preserved is straight."

It is noticeable that the denticles of the outer row become confluent in a low ridge on the lower portion of the spine.

[No. 6502.]

Pleuracanthus (Orthacanthus) gracilis Newb. Plate I, Fig. 4.

Orthacanthus gracilis Newb., Geol. Surv. Ohio, Pal., Vol. II, p. 56. Plate LIX, Fig. 7.

Orthacanthus gracilis Newb., Cope, 1881, Am. Nat., p. 163.

"Spine small and straight, about three inches long, very slender and acute; section circular at base, posterior face and sides flattened above, the angle inclosed by them set with acute, recurved, compressed denticles throughout the upper two thirds of the entire length; surface smooth or finely striate longitudinally."

The name *Orthacanthus* was used by Newberry only provisionally for spines which were supposed to belong with teeth called *Diplodus*, and was to be suppressed when the two should be found together.

It is noticeable that the denticles are fewer and larger than those on the spine of *P. quadriseriatus*, and that there is but a single row of denticles on each side.

[No. 6503.]

Pleuracanthus (Didymodus) compressus Newb. Plate I, Figs. 5*a*, 5*b*, 5*c*, 5*d*.

Diplodus (?) *compressus* Newb., Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Didymodus (?) *compressus* Newb., Cope, 1883, Proc. Phil. Acad. Nat. Sc., p. 108.

Represented in the collection by several imperfect teeth. Cope offered no additional description of the form, contenting himself with the statement that "one with a lateral and median denticles nearly complete, agrees pretty well with the species cited." In 1883 he substituted the name *Didymodus*, as the name *Diplodus* was preoccupied, having been used by Rafinesque for a genus of fishes.

The teeth are much smaller than the species of the same genus found in Texas.

Later several complete crania of the genus were obtained from Texas and described in detail by Professor Cope, Trans. Am. Phil. Soc., 1884, pp. 572–590, 1 plate (Pal. Bull., No. 38). In the American Naturalist of the same year, p. 413, the genus was made the type form of the new order *Ichthyotomi* of the *Elasmobranchii.*

The form is now quite usually recognized as belonging to the genus *Pleuracanthus* Ag., one of the common forms of the Carboniferous and Permian faunas of Europe and America.

[No. 6504.]

Thoracodus emydinus Cope.

Thoracodus emydinus Cope, 1883, Proc. Acad. Nat. Sc., Phil., p. 108.

Thoracodus emydinus Woodward 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 39.

"The form of the tooth or jaw on which this genus is proposed, reminds one of that of a *Diodon*, and also of one half of that of a *Janassa.* It appears to be the half of a bilateral plate, which is divided on the middle line by suture. Its form is somewhat that of the anterior part of an episternal bone of a tortoise. It consists essentially of a smooth border, separated from the remainder of the tooth by a transverse groove. The interior portion is, on the superior face (if the piece belong to the inferior jaw, and *vice versa*), transversely ridged and grooved, after the manner of the genus *Janassa.*"

Specific characters: "The smooth border is wide above and below. Its edge is produced into a median projection, which is decurved. On the inferior surface it is marked by shallow grooves, which radiate from the groove which bounds it posteriorly, extending nearly to the free edge. Posterior to the bounding groove, the surface is smooth. The posterior surface above has its grooves concentric with the curved free margin. The ridges are narrow, and step-like in position, presenting their free edges backwards. There are no grooves other than these steps. They have an angular curve opposite to the angle of the free margin, and at the angle the groove which separates them is narrowed, while it widens at other points. Free edge of border thickened; surface everywhere smooth."

MEASUREMENTS.

"Length of fragment transversely	$.014^{m}$
Length of fragment antero-posteriorly	.011
Width of border area at median suture	.005
Seven cross ridges	.005
Thickness at suture at cross ridges	.002 "

[This specimen is missing from the collection.]

Sagenodus vinslovii Cope. Plate I, Figs. 6*a*, 6*b*.

Ceratodus vinslovii Cope, 1875, Proc. Phil. Acad. Nat. Sc., p. 410.

Ceratodus vinslovii Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Ptyonodus vinslovii Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

Sagenodus vinslovii Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 262.

Sagenodus vinslovii Williston, 1899, Kans., Univ. Quart., Series A, p. 176.

"The crown of the tooth is in general outline an oval, wider at one end than the other, the inner border gently convex and entire. The outer border is marked by six shallow notches which are separated by as many sharp, compressed projections. The emarginations and denticles are the termini of corresponding grooves and ridges, which radiate from a smooth space along the inner margin of the crown. From this plane the grooves gradually deepen to the margin; the separating ridges are acute and without irregularity or serration. The base or root of the tooth is quite wide. Externally it extends beyond the border of the crown at the notches, and has projections corresponding to the denticles, from which it is separated by a horizontal notch. On the inner side the base extends like a shelf beyond the posterior half of the crown, and is produced backwards beyond its posterior border. The inferior plane is concave in transverse section; the crown is plane in all directions."

MEASUREMENTS.

"Length of crown preserved	.021^{m}
Width crown	.013
Length of root preserved	.022
Depth of root internally	.005
Depth of root externally	.003 "

"This *Ceratodus* (*Ptyonodus*) resembles the species described by Agassiz under the name of *C. parvus* and *C. serratus* from the English Trias, but differs from them in the shortness of the tooth-like processes. In none of the species do I find such a development of the basis on the inner side."

[No. 6507.]

Sagenodus vabasensis Cope. Plate I, Fig. 7.

Ctenodus vabasensis Cope, 1883, Proc. Phil. Acad. Nat. Sc., p. 110.

Sagenodus vabasensis Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus vabasensis Williston, 1899, Kans. Univ. Quart., Series A, p. 176.

"This fine species is represented by an almost perfect tooth. It is allied to the *C. fossatus* Cope, but is wider, and the crests do not radiate so equally, but are chiefly directed in one direction, as in most species of the genus. The *C. gurleianus* and *C. pusillus* are at once distinguished by the small number of crests, while the *C. periprion* and *C. dialophus* have a larger number of crests, and are otherwise different. *C. porrectus* differs less from it, but has only five + crests, while *C. vabasensis* has six +. The + represents the small posterior (?) crest, which is double. This, with the next one, is directed slightly posteriorly; the fifth is at right angles to the long axis, and the anterior four extend more or less forwards. They are serrate nearly to their bases, but the teeth are obsolete on their basal halves. The straight part of the internal edge extends as far forwards as the fourth crest, and is continued posteriorly as a short process. No fossæ at ends of crests. Superior face of tooth wide and slightly concave. The anterior part of the first and second crests are broken away, so that it is impossible to say whether they are produced as in *C. porrectus*."

MEASUREMENTS.

"Length to marginal base of second crest	.024^{m}
Width at marginal base of second crest	009
Width at fourth crest, inclusive of apex	.015
Width of posterior side	.010
Thickness at base of fifth crest	.005 "

[No. 6510.]

Sagenodus gurleyanus Cope. Plate I, Figs. 8*a*, 8*b*, 8*c*.

Ctenodus gurleyanus Cope, 1877, Proc. Am. Phil. Soc., p. 55.

Sagenodus gurleyanus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus gurleyanus Williston, 1899, Kans. Univ. Quart., Series A, p. 176.

"This species is indicated by a portion of a tooth, which leaves the number of the ridges a matter of uncertainty. On this account its description might have been postponed, but that the distinctness of its characters render it clear that it cannot be placed with any other species. The crown, as in *Ceratodus* (*Sagenodus*) *paucicristatus*, is narrow and rather thick; but three

crests are present, all radiating in the same general direction, the longer close to the inner border. There was not more than one additional crest, or one and a rudiment, and these have probably the same direction as those which are preserved. The crests are sharp, elevated, and coarsely dentate; they are not decurved at the extremity, but cease abruptly with a projecting denticle, beneath which the basis is excavated by a shallow fossa. The inferior face is slightly concave, the internal wall vertical."

MEASUREMENTS.

"Greatest width - - - - - - - -	.008^{m}
Depth at inner border - - - - - -	.005 "

[No. 6509.]

Sagenodus pusillus Cope. Plate I, Figs. 9*a*, 9*b*.

Ctenodus pusillus Cope, 1877, Proc. Am. Phil. Soc., p. 191. (Pal. Bull., No. 26.)

Sagenodus pusillus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus pusillus Williston, Kans. Univ. Quart., Series A, p. 176.

"Form narrow, the width of the base about equal to the depth. The coronal portion is narrower than the base, because the inner face is oblique, forming an acute angle with the inferior plane. There are but four crests, of which the two longer are directed in one direction, and the two shorter in another. The interior ones of both pairs form a continuous crest which is convex inwards. The crests are straight, elevated and acute; each one supports two or three denticles, which are rectangular and little elevated. The longer ones project beyond the general outline; the shorter ones are less prominent at the extremities; all are obtuse in the vertical direction. The superior surface is smooth. The inferior is slightly concave in the transverse sense. The tooth on which this species is founded is the smallest yet obtained from the formation (Permian of Illinois). Length, .007^{m}; width, .003^{m}; depth at the inner crest, .003^{m}."

[No. 6508.]

Sagenodus fossatus Cope. Plate I, Figs. 10*a*, 10*b*.

Ctenodus fossatus Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Sagenodus fossatus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus fossatus Williston, 1899, Kans. Univ. Quart., Series A, p. 176.

"Represented by a nearly perfect tooth of a general narrow and vertically thickened form. There are five crests, the largest three extended in one

direction, and the other two in the other. Between the last of the latter and the inner border is a rudiment of another in the form of a rugosity. None of the crests touch each other at their bases. At their extremities they curve rather abruptly downward, and do not project beyond the inferior plane, from which each one is separated by a deep fossa, whose mouth is a notch in its base. The crests are coarsely dentate, there being three or four teeth on each, and the grooves between them are marked by coarse transverse undulating grooves. The inner border is a deep vertical plane; the inferior face is narrow and concave in transverse section."

MEASUREMENTS.

"Total length	.022^{m}
Greatest width	.007
Depth at middle	.006 "

"It differs from the *C. serratus* of Newberry in its narrow form, small number of ridges and the very slight prolongation of their extremities."

[No. 6506.]

Sagenodus heterolophus Cope.

Ctenodus heterolophus Cope, 1883, Proc. Acad. Nat. Sc., Phil., p. 109.

Sagenodus heterolophus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus heterolophus Williston, 1899, Kans. Univ. Quart. Series A, p. 176.

"This species is represented by a single broken tooth, which presents remarkable characters. It had apparently, when perfect, but three crests, which differ greatly in length, diminishing very rapidly from the first or marginal crest.

"The crest just mentioned is not only longer, but *much more* elevated than the others, except at the base, where the second crest is the highest. But while the first rapidly rises, the second retains its elevation, and then descends, forming a convex edge, of which the distal part is obtusely serrate. The proximal part of the first crest is worn by friction with the opposing edge of the opposite jaw into a sharp edge, below which its base is covered by a thin layer of the shining cementum which invests the teeth and sides of the second crest. The amount of this shinning layer is thus more extensive than in any other species of *Ctenodus* known to me. The third crest, judging by its base of continuity with the second, is very small."

MEASUREMENTS.

"Elevation of first crest at middle	.0095^{m}
Elevation of second crest at middle	.0065
Length of a tooth of second crest	.0020 "

[This specimen is missing from the collection.]

Sagenodus paucicristatus Cope. Plate I, Figs. 11*a*, 11*b*.

Ceratodus paucicristatus Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Ptyonodus paucicristatus Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

Sagenodus paucicristatus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus paucicristatus Williston, 1899, Kans. Univ. Quart., Series A, p. 175.

"The single tooth representing this species is narrow in the transverse direction, but stout in vertical diameter. But four ridges are present, all of which have a single direction, but the shorter ones are the less oblique to the long axis of the tooth. They all extend into the inner border but become low as they approach it. Distally they are quite prominent, but do not project very far beyond the emarginate border between them. The inner border is plane and vertical, and without ledge; the inferior surface is concave in the transverse direction. The surface of the tooth is minutely and elegantly corrugated."

MEASUREMENTS.

"Length from the base of second rib - - - -	.017 m
Depth at base of second rib - - - - - -	.0045 "

[No. 6505.]

Peplorhina arctata Cope.

Peplorhina arctata Cope, 1877, Proc. Am. Phil. Soc., p. 55.

Theromorphous Saurian, Proc. Am. Phil. Soc., 1882, footnote to p. 461. (Pal. Bull., No. 35).

The species was based on an imperfect bone bearing small teeth. From its resemblance to the palatal teeth of *Peplorhina anthracina* the author refers it to that genus with the remark that "this course is open to modification should subsequent investigation require it." Later, in 1882, he remarks in a footnote; "*Peplorhina arctata* Cope from the Illinois Permian is not a *Peplorhina* but a *Theromorphous Saurian*."

The broken specimen originally described certainly has much the appearance of the small teeth which occur in the roof of the mouth of certain of the *Cotylosauria* and may very possibly belong there, but there is present in the collection a complete plate showing no sutural edges. It is certainly a plate from the mouth of a *Crossopterygian* fish, and as the description of the perfect portions of Cope's specimen applies very perfectly to it, it may best be considered under the original name. The applicable portion of the original description is as follows: "The convex surface (of the plate) is thickly

studded with teeth, which are not in contact with each other. Their size increases from one side of the bone to the other, and still more, from one extremity to the other. The crowns are swollen at the nearly sessile base, and contract rapidly to a conical and unsymmetrical apex. One side of the latter is slightly concave below the apex. The surface is shiny and distinctly grooved. Fractured crowns do not display any central cavity."

The present specimen is rather oval, one side showing a perfect convex outline and the other with three straight edges at large angles to each other. The whole plate is convex on the toothed side and concave below. The angulated border is thickened and roughened and the rounded border thin. The surface is covered with teeth, larger in the middle and on the thickened border than on the other edges. The plate is .0158^{m} long and .0114^{m} wide.

[Nos. 6511 (Cope's type) and 6512.]

Cricotus heteroclitus. Plate I, Figs. 12*a*, 12*b*, 12*c*, 12*d*, 13, 14.

Cricotus heteroclitus Cope, 1875, Proc. Phil. Acad. Nat. Sc., p. 405.

Cricotus heteroclitus Cope, 1877, Proc. Am. Phil. Soc., p. 64.

Cricotus discophorus Cope, 1877, Proc. Am. Phil. Soc., p. 186. (Pal. Bull., No. 26.)

Cricotus heteroclitus Cope, 1878, Proc. Am. Phil. Soc., p. 522. (Pal. Bull., No. 29.)

The genus was founded on some intercentra which were regarded as centra of the caudal region; it was not until 1878 that the true nature of the intercentra was made out. With the intercentra were a few other bones doubtfully referred to the same genus. That portion of the original description which is applicable to the bones as intercentra is as follows: "The caudal vertebra (intercentrum) best preserved is stout, discoidal in form, and deeper than wide. It resembles in form that of an herbivorous dinosaurian, but differs otherwise. The articular faces are deeply concave, the posterior most strikingly so; and the middle is occupied by a large foramen, whose diameter is about equal to that of the centrum on each side of it. The lateral borders of the posterior articular face are expanded backwards, and articulate with a bevel of the corresponding edge of the anterior articular extremity. In this way the vertebra combines the mechanical relations of the biconcave with opisthocœlian structures. These neural arches (hæmapophyses) are narrow and directed backwards; their bases are firmly coössified with the centrum." . . . . "On the inferior (superior) surface of the centrum (intercentrum) two shallow pits occupy considerable space. . . . ." It will be noticed that the describer had the intercentrum inverted; this fact was later understood by himself and certain drawings corrected. The structure of the skull and other

portions of the skeleton of the species are described by Cope in the Proc. Am. Phil. Soc., 1878, p. 523 and figured in the same, 1882, Plate II. The synonymy of *C. heteroclitus* and *C. discophorus* was also recognized by Cope in Proc. Am. Phil. Soc., 1878, p. 523.

[No. 6517 (the type specimen), 6518 (type of *C. discophorus*), 6519, and 6520].

Cricotus gibsoni Cope, Plate I, Figs. 15*a*, 15*b*, 15*c*.

Cricotus gibsoni Cope, 1877, Proc. Am. Phil. Soc., p. 185. (Pal. Bull., No. 26.)

Represented in the collection by several vertebræ, all of one form. Cope considered the type specimen as probably from the caudal region. He says, "On this vertebra there is no trace of diapophysis, and the neurapophysis rises from the external side of the superior face. The wall of the neural canal is not preserved, but the inference is that the diameter of the latter is large. This fact and the absence of definite chevron articulations leads me to doubt the caudal position of the vertebra; but the usual marks of the dorsal and cervical vertebrae are totally wanting from it. As in *C. heteroclitus*, the *foramen chordæ dorsalis* is large, its diameter being one third of the total. The articular faces descend steeply into it, that of one extremity more so than the other. The rim of the latter face is beveled outwards, the plane thus produced appearing on the inferior face something like the united faces of the chevron bones.

"The centrum is a little deeper than wide, and the inferior face is truncate so as to give a subquadrate outline. The inferior plane is concave, the concavity being divided by a longitudinal rib. The sides are somewhat concave, with a longitudinal rib at the middle. Diameters of centrum: vertical .010^{m}; transverse .009^{m}; longitudinal .008^{m}. Width of inferior plane .005^{m}; width above, including neurapophyses .008^{m}.

"As compared with *C. heteroclitus* this species differs in the presence of parallel ridges inclosing a median fossa on the inferior side of the centrum. The small size may be considered, but it is uncertain whether the two animals represented by the vertebrae are fully grown."

[Nos. 6521 and 6522.]

Cricotus sp. Plate V, Figs. 13*a*, 13*b*, 14*a*, 14*b*, 15, 16.

There are several phalanges of *Cricotus*. They are much stouter than those of *Clepsydrops;* even in the members of the distal series, where the phalanges are very short, they are still very stout, almost as broad as long. They show a delicate sculpture over the entire surface; the articular surfaces are less well defined than in the reptilian forms. In the middle series they

are longer in proportion than at either end, rather curved, flattened, and with the shaft little less in width than the extremities.

[No 6523.]

Diplocaulus salamandroides Cope. Plate I, Figs, 16*a*, 16*b*, 17*a*, 17*b*. Plate V, Figs. 17*a*, 17*b*, 17*c*, 17*d*.

Diplocaulus salamandroides Cope, 1877, Proc. Am. Phil. Soc., p. 187. (Pal. Bull., No. 26.)

Diplocaulus salamandroides Cope, 1882, Proc. Am. Phil. Soc., p. 451. (Pal. Bull., No. 35.)

Cope's generic description is as follows: "Vertebral centra elongate, contracted medially, and perforated by the foramen chordæ dorsalis; coössified with the neural arch, and supporting transverse processes. Two rib articulations one below the other, generally both at the extremities of the processes, but the inferior sometimes sessile. No neural spines nor diapophysis; the zygapophyses normal and well developed."

Specific description: "The surface of the centrum is smooth and is without grooves. The diapophyses and parapophyses are rather elongate, and are closely approximated one above the other. The superior process issues from the centrum opposite the superior margin of the articular faces. They stand equidistant from the extremities of the centrum, and are directed obliquely backwards. The anterior zygapophyses occupy the same level. The neural spine is a compressed longitudinal ridge; it divides behind, leaving a notch between the posterior zygapophyses."

MEASUREMENTS.

"Diameter of centrum	longitudinal	.0060^{m}
	vertical	.0025
	transverse	.0025
Depth of centrum and neural arch		.0060
Width with transverse processes		.0070
Expanse of posterior zygapophyses		.0050 "

A portion of a small skull was in contact with one of the vertebra. The ramus of the jaw is shallow and stout, the external surface sculptured with inosculating lines. Teeth with cylindrical roots set in shallow alveoli. The crowns elongate, slightly compressed near the apex, and without grooves or lines.

In describing the vertebræ of *D. magnicornis* from Texas (Proc. Am. Phil. Soc., 1882, p. 453) Cope calls attention to the presence of zygosphene and zygantrum in that species; they are also present in the *D. salamandroides*, but are so small as to easily escape notice. The surface of the centrum is stated to be smooth in the Illinois species, this is largely due to weathering, as the more perfect specimens show the same beautiful sculpture as in the Texas forms,

The articulations for the ribs are separate in the cervical region, and become more and more closely united posteriorly. The resemblance between *D. salamandroides* and *D. magnicornis* is very striking, almost the only observable difference being in the size, the latter being from five to six times the size of the former. This statement is limited to the vertebral column, as the skull of the Illinois species is unknown.

In the Proceedings of the Am. Phil. Soc., 1882, p. 452 (Pal. Bull., No. 35), Cope gives a history of the classification of *Diplocaulus* and a summary of the characters of the genus as derived from specimens from the Permian of Texas.

[Nos. 6513, 6514, 6515, and 6516.]

Clepsydrops colletii Cope. Plate II, Figs. 1*a*, 1*b*, 1*c*, 2*a*, 2*b*, 3*a*, 3*b*.
Clepsydrops colletii Cope, 1875, Proc. Phil. Acad. Sc., p. 407.
Clepsydrops colletii Cope, 1877, Proc. Am. Phil. Soc., p. 62.

This genus was based on a series of vertebræ supposed to represent the cervical caudal and dorsal regions. With them were associated other bones, which in all probability did not belong to the same specimen, though they may have belonged to the same species of the genus. The vertebræ were compared with those of the *Cricotus*, or rather with the intercentra of *Cricotus*, as Cope was not entirely sure at the time of the amphibian nature of *Cricotus*. The original description of the vertebræ given by Cope to characterize the genus *Clepsydrops* is as follows: "They are deeply biconcave, the articular cavities being funnel-shaped and continuous, thus perforating the entire length of the centrum. In a dorsal vertebra the cavities communicate by a very small orifice, while in the posterior the median contraction of the canal is less marked. The posterior cavity is more gradually contracted than the anterior; in the latter the excavation is, in most of the vertebræ, but slight (except beneath the floor of the neural arch), until it falls rather abruptly into the axial perforation. In an (?) anterior dorsal it is as widely excavated at the border as the posterior funnel. Another peculiarity s the abscence of the processes of the centrum; and a small capitular articulation is seen sessile on the border of the cup of two of the dorsals.

"The axis has a singular form, owing to the tubular perforation which continues the posterior excavation to the anterior face of the centrum. There are three articular faces, a larger subround inferior and two smaller superior, which border the neural canal in front and below and are separated from each other and the inferior face by the perforation in question. The anterior face slopes obliquely backwards and downwards, and is convex in transverse section. There is no facet for the free hypapophysis of the odontoid, but it appears that the inferior articular face was applied exclusively to the centrum of the atlas, as in *Sphenodon*. But the axis differs from that of the

latter genus in the abscence of a coössified odontoid process. Either that element is entirely wanting or it consists of two pieces, interrupted in the middle by the notochordal foramen, and in correspondence with superior articular facets. There is no true hypapophysis of the axis, and the only indication of lateral processes is a small articular facet on each side on the lower part of the rim of the posterior funnel. These may have been related to rudimental cervical ribs. The neural arch is broken off.

The dorsal vertebræ have their sides somewhat contracted; in one specimen the inferior face is rounded, in another, which I suppose to belong to a different part of the column, it is longitudinally acute. In this and another dorsal, where the parts are exposed, the floor of the neural canal is interrupted by a deep fissure, which has a triangular shape with apex downward when seen in profile. This is due to the fact that the opposite halves of the centrum are united by the circumferences of the articular cups, which have in profile an X shape. The diapophysis does not project far beyond the base of the neural arch and is compressed. The caudals are elongate, and resemble, in the forms of the centrum and neural arch, those of *Lælaps*. The neural spines are not preserved, but if present were directed well backwards, bearing the posterior zygapophyses, since the arch stands only on the anterior three-fifths of the centrum. Chevron facets are not distinct, but two emarginations on the rim of the posterior face of one of the vertebræ indicate their existence. In other centra even these notches are wanting. The tail was evidently tapering. There is no evidence of the transverse fissures seen in *Sphenodon* and many *Lacertilia*, nor are there any diapophyses on the caudal vertebræ preserved.

Specific characters: "There is a shallow fossa in the entering angle between the superior and inferior articular facets of the front of the axis, and the centrum of the same is obtusely keeled below. The border of the anterior face of the dorsal vertebræ with keeled centrum is undulate. The obtuse inferior face of another dorsal is rugulose, and the edge of the face is not undulate. The inferior faces of the two caudals are marked with fine parallel grooves, while in another caudal and the (?) sacrals the same is smooth. There are some longitudinal ridges on the upper side of the larger caudal."

MEASUREMENTS.

"Length of centrum of axis	$.006^{m}$
Width do. at middle behind	.008
Depth do. (oblique)	.010
Length centrum of sharp keeled dorsal	.014
Depth do. behind	.012
Width do. behind	.012
Length centrum rounded dorsal	.012
Depth do. behind	.011
Width do. behind	.010
Width neural canal do.	.004

Length centrum larger caudal - - - - -	.014^{m}
Width do. - - - - - - - - - -	.008
Depth do. - - - - - - - - - - -	.008
Length smaller caudal - - - - - - -	.010
Depth centrum do. - - - - - - - -	.007
Width do. - - - - - - - - - -	.007 "

[Nos. 6530 (type specimen), 6531, and 6578.]

Clepsydrops pedunculatus Cope. Plate II, Figs. 4*a*, 4*b*, 4*c*, 4*d*; Figs. 5*a*, 5*b*, 5*c*, 5*d*.

Clepsydrops pedunculatus Cope, 1877, Proc. Am. Phil. Soc., p. 63.

This genus was established on two vertebræ, a third cervical, and an anterior caudal, regarded by Cope as a dorsal.

"Both differ from corresponding vertebræ of *C. colletti* and *C. lateralis* (this is evidently a slip on the part of the describer; there is no *C. lateralis; C. vinslovii* is evidently referred to, as it was the only other species of the genus described at this date) in having elongate diapophyses for the attachment of the ribs. These are present in the other species, but are either very short, or sessile. The third cervical has a broad reverted anterior lip-like margin of the anterior articular face, which resembles the corresponding part in *C. lateralis* (*vinslovii*) in not being produced below. The median line is keeled, and there is a shallow longitudinal groove on the upper part of the sides. The posterior articular face is regularly funnel shaped. The diapophyses are very stout, and are directed a little downwards and strongly backwards. The articular faces are single, look downwards and outwards, and are wide above, and narrow below. The base of the neural canal is deeply incised, as in the other species."

MEASUREMENTS.

" Diameter of centrum	antero-posterior - - - -	.015 ^{m}
	transverse - - - -	.0125
	vertical - - - - -	.012
Length of diapophysis above - - - - -		.009
Diameter of diapophysis	vertical - - -	.008
	antero-posterior -	.005 "

In the description of the supposed dorsal attention is called to the long and slender diapophysis; it is evident that this is not a diapophysis, but an anchylosed rib with the distal broken portion inclined forward, as is characteristic of the anterior caudal ribs of the *Rhyncocephalia*. Speaking of other portions of the vertebra, the describer says: "There is no recurved rim of the articular extremities, but the surface does not pass regularly into the foramen chordæ dorsalis, but by an abrupt descent at its mouth. The

sides of the centrum are concave, and the inferior portion forms a prominent rounded rib."

MEASUREMENTS.

" Diameter of centrum	antero-posterior	.016^{m}
	transverse	.015
	vertical	.016 "

[Nos. 6534 (type specimen) and 6535.]

Clepsydrops vinslovii Cope. Plate II, Figs. *7a*, *7b*, *7c*, *7d*.

Clepsydrops vinslovii Cope, 1877, Proc. Am. Phil. Soc., p. 62.

This species was based on a single cervical vertebra with which others were uncertainly identified. The specific characters given are as follows: "The inferior median line is a keel; some distance above it, the sides of the centrum are full, rising in a longitudinal angle. There is no constriction or fossa below the diapophysis as in *C. colletti*. The latter is anterior in position, is vertically compressed, and is curved forward for a short distance below. The posterior articular face is regularly funnel-shaped from the margin; the anterior face has a broad recurved lip. This passes around the inferior margin, which is not projected forwards as in *C. colletti*. The zygapophyses are well developed, and stand close together. The neural spine is compressed, and the basal portion points somewhat forwards."

MEASUREMENTS.

" Length of centrum		.011^{m}
Diameter of posterior articular face	vertical	.009
	transverse	.009
Vertical diameter of diapophysis		.006
Expanse of posterior zygapophysis		.009
Antero-posterior diameter of base of neural spine		.005
Transverse diameter of neural arch		.006 "

[Nos. 6532 (type specimen) and 6533.]

Lysorophus tricarinatus Cope. Plate II, Figs. *12a*, *12b*, *12c*.

Lysorophus tricarinatus Cope, 1877, Proc. Am. Phil. Soc., p. 187. (Pal. Bull., No. 26.)

The type specimens consist of two vertebræ and a portion of a third. The generic characters given by Cope are as follows: "Vertebræ amphicœlian, perforated by the foramen chordæ dorsalis. Neural arch freely articulated to the centrum. Floor of neural canal deeply excavated. No processes or costal articulations on the centrum, which is excavated by longitudinal fossæ. Centrum not shortened." Specific characters: "Two centra and a portion of a third represent this species. The former are a little longer than wide and a little depressed. The facet for the neural arch is an elongate plane truncating the border of the fossa of the neural canal on each side,

for one half to three fifths the length of the centrum. Two deep longitudinal fossæ extend on each side of a median rib of the inferior face; and they are separated above by a narrower rib from another longitudinal fossa which is below the base of the neural arch.

MEASUREMENTS.

" Diameter of centrum	longitudinal	.0055m
	vertical	.0038
	transverse	.0040
Length of facet for neurapophysis		.0035
Width of neural canal		.0020 "

This form differs very decidedly from any other in the collection in the prominence of the keel and the lateral ridges; they, or rather the fossæ between them, are developed to an extent that almost destroys the centrum, leaving but a very slender tube surrounding the notochord. A few centra of larger size show strongly developed keels and free neural arches, but much stouter proportions.

[Nos. 6526 (the type specimen; it is badly broken), 6527, and 6528.]

Archæobelus vellicatus Cope. Plate III, Fig. 1.

"*Species No. 4*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

Archæobelus vellicatus Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

This genus is represented by teeth alone. In his discussion of the form Cope says, in the earlier paper, "there is nothing to prevent their (the teeth) reference to the *Lacertilia*." The generic description is as follows: "The form is conical, and the surface is not grooved nor furnished with prominent ridges. The interior is hollow, and the walls are composed of a few concentric layers without external enamel or cementum. The solid base to which it is attached is shallow, presenting smooth surface on the opposite side, which is deeply impressed by a longitudinal groove at one end." The specific description is given in the earlier paper: "The crown is conic, subround in section, and curved backward. There are no cutting edges, and the base is a little flattened in front and behind. On each of the faces thus formed, there is an open, shallow groove, sometimes obsolete. There are no other grooves or sculpture on the teeth. . . . . One of the specimens displays an extensive pulp cavity."

MEASUREMENTS.

	First specimen	First specimen	Second specimen
" Diameter of base	.004m long	.008m short	.005m
		First specimen	Second specimen
Length of crown		.010m	.015m "

There are several specimens of the isolated teeth described by Cope in the collection, but in addition a considerable portion of a maxillary bone which

shows many points of interest. In all the single teeth, as described by Cope, they are attached to a portion of the jaw and unaccompanied by any other teeth, but there is posterior to the tooth a cavity which, as shown by the more perfect jaw, accommodated a second tooth larger even than the first. In the fragment of the jaw there are, first, three quite small teeth, and then, supported by a swollen portion of the rim, there are two very large canine teeth; posterior to these, three teeth about equal in size to those anterior to the canines, and then five smaller ones. As both ends of the piece are incomplete, it is certain that there were more teeth than here recorded. Several differences from *Clepsydrops* and *Dimetrodon* are apparent: first, the anchylosis of the teeth to the jaw, instead of being inserted in well defined alveoli; second, the presence of two enlarged canines instead of one, and third, the possible absence of the diastema anterior to the canines; for in the *Dimetrodon* the anterior teeth of the maxillary decrease to small size immediately and the notch of the diastema begins just anterior to the canine and below the external nares, but here, though the anterior tooth is almost below the nares, there is no sign of the beginning of the notch, if any existed. The teeth are all more or less rounded in section and show no sign of a cutting edge. In general appearance the jaw is much like that of the Pelycosaurians; *i. e.*, with a thin outer wall and a heavy shelf-like dentigerous edge.

Associated with the fragments of the upper jaws are several portions of the lower jaws showing the symphasial region. Some of the anterior teeth, about the third and fourth, seem to have been slightly larger than the others, but as such a small part is preserved it is impossible to say definitely. These fragments may have belonged to the genus *Clepsydrops*, and, indeed, the fragments of the upper jaws also.

[Nos. 6524 and 6525.]

UNNAMED SPECIMENS.

Besides the specimens named and described by Cope there are present in the collection many isolated bones from different parts of the skeleton which cannot be identified with certainty as belonging to any of the forms described; that they belong to some of them is practically certain. The fact that the bones are nearly always found isolated and generally in a fragmentary condition prevents any attempt at a restoration of the skeleton, but their resemblance to corresponding bones from the Texas deposits makes it probable that the animals from the two regions did not differ materially in form. One fact is noticeable, the

absence of animals of any great size as compared with the Texas forms.

Skull.—The skull is represented by two nearly perfect maxillaries, apparently the bones from the two sides of the same specimen, and several fragments showing the occipital condyles.

The premaxillaries are similar to those of *Dimetrodon* and of *Empedias* as figured by Cope. The external surface is pitted, and there was evidently a large opening of the external nares. The teeth do not show any great disparity in size nor are they chisel-shaped; there is no evidence of the presence of a diastema as in the *Pelycosauria* in general, but this may be due to the imperfection of the bone. Plate III, Figs. 2, *a* and *b*. [No. 6536.]

The occipital condyles are well rounded, hemispherical in outline, the upper edge being slightly concave, and marked by a pit near the upper edge. [No. 6537.]

Vertebræ.—There are a great many vertebræ, either isolated specimens or small lots belonging together; the majority evidently belong to one or the other of the three species of *Clepsydrops* described. There are two lots that seem different from the others.

Two vertebræ very much larger than the others apparently belong to the lumbar or posterior dorsal region. They are characterized by the breadth of the centrum as compared by its height. The lower surface is marked by a rounded but prominent keel. One shows measurements corresponding very closely with those given by Cope for *C. natalis* from Texas. It is very possible that they represent this species. [No. 6538.]

A second set of vertebræ resemble in large measure those of *Lysorhophus tricarinatus* in the free articulation of the neural arch to the centrum and the general form of the centrum; they differ, however, in the absence of the strongly marked keels and the deeply incised fossæ between them. They vary greatly in size, some being as large as those of *L. tricarinatus* and others three or four times as large. If it were not for the presence of vertebræ of different size they might be regarded as dorsals of the described species. As it is, they seem to indicate a possible new species.

MEASUREMENTS.

"Length of a centrum	.011^m
Breadth of a centrum	.011
Length of a second centrum	.007
Breadth of a second centrum	.006 "

Plate II, Fig. 13, *a*, *b*, and *c*. [No. 6529.]

Scapula.—There are many incomplete scapulæ in the collection. They are all of small size, but resemble in form those figured by Cope (Proc. Am.

Phil. Soc., Aug. 1884, and Proc. Am. Assoc. and Sc., 1 and Case (Trans. Am. Phil. Soc., 1899, Vol. XX.) One s proximal end with articular cavity for the humerus forı and coracoid. The scapula is perforated by a foramen j ular face. Plate III, Fig. 3. [No. 6540.]

Humeri.—There are four types of humerus. One, the much shorter and stouter than the others, and is remark articular faces and the generally robust character. Tl marked by prominent rugosities and the deltoid crest is much more so than in the other forms, and very rough. of the head at the deltoid ridge .057^m. Plate III, Fig. 4,

The second form has a much longer shaft than the fir shows a greater elegance of form at the expense of streng ities are as well formed and the articulate surfaces as disti belongs to one of the described forms of *Clepsydrops* froı the largest, *C. pedunculatus*. A smaller form of the same by the distal end of another humerus, which is perfect entepicondylar foramen is large and elongate, the ectepi represented by a notch, as in all the *Pelycosauria*; the he end of the radius is prominent, almost hemispherical an continuous with the articular surface for the ulna. Height width at deltoid ridge .030^m. Plate III, Fig. 5, *a*, *b*, *c*, 6542, 6543, and 6575.]

The third type is represented by the distal end of a v ilar in many respects to the foregoing, but with the interı and truncated and the entepicondylar foramen missing. small and the shaft of the bone was slender, but the dista strong development. The process forming the ectepicond nent, and the portion of the distal extremity on either si surface extended below the surface instead of lying in reaching so far. This form may be the same as the "N Cope in his first contribution to the fauna of the Texas Pe not described nor figured, it is impossible to say definit "No. 6" is regared by Cope as belonging to a possibly f may be true of the present form, but there is no vertab which could go with such a type. Plate III, Fig. 7. [N

The fourth and last type differs very considerably fro ends are concave, as if they had been cartilaginous in li articular surfaces distinguished. The extremities are at other, and there is a small deltoid process, continuous end. The entepicondylar foramen is present, but ther

ectepicondylar notch. Length .038^{m}, width proximal end .0105^{m}, distal end .0205^{m}. Plate III, Fig. 8, *a*, *b*, *c*, *d*. [No. 6545.]

Ulnæ.—There are two types of ulna distinguished by the size only. One is nearly as large as the ulna of *Dimetrodon incisivus* and quite similar to it; the proximal end only is preserved; the other is smaller, represented by the proximal end also, and probably belongs to one of the smaller species of *Clepsydrops*. Plate III, Fig. 9. [Nos. 6546 and 6547.]

Femoræ.—The femora are mostly of the same type, but show considerable variation in size. They all have the distal articular surfaces upon the inner or lower face of the distal end, showing that the leg was habitually flexed and the animal progressed, probably, with the belly on or near the ground, in the manner of the alligator. One of the medium sized forms is figured (No. 6548). Length of one specimen, .077^{m}; a larger specimen, .107^{m}. Plate IV, Fig. 1, *a* and *b*. [Nos. 6548, 6549, 6550, 6551, 6552, and 6553.]

The distal ends of two very small femora are present; they lack well-developed articular surfaces, though the contour of the extremity is the same as in the larger specimens. It seems probable that they are immature forms. [No. 6552.]

Tibia.—There is one complete tibia, somewhat crushed, and the proximal end of another. The whole bone is larger at the proximal than at the distal extremity, and is considerably curved. The shaft is more or less flattened. The proximal end has two faces, which are distinct, or nearly so; they are oblong and lie with their long axes nearly at right angles to each other. The anterior extremity of one anticular face forms the upper portion of the cnemial crest. Measurements: length, .049^{m}. Plate IV, Fig. 2, *a* and *b*. [No. 6555.]

Fibula.—What appears to be a fibula is .053^{m} long. It is a slender bone, expanded at the extremities and quite strongly curved. Plate IV, Fig. 3. [No. 6554.]

Ilia.—There are two types of ilia of about the same size. Each presents two articular faces at the distal portion for articulation with the ischium and pubis and a rather deeper articular portion of the acetabulum; at the upper portion of the acetabulum there is a prominent overhanging process. The two forms differ principally in the anterior process of the ilium with which it is attached to the sacral vertebræ. In one form it extends almost straight forward (No. 6556) and in the other (No. 6557) it is curved and the anterior end is somewhat lower than the posterior. The inner side of each presents strong longitudinal ridges and there does not seem to be any articular facet for the vertebræ. In an incomplete fragment, in which the ischium and ilium are in contact, the acetabulum is seen to be quite deep. Plate IV, Figs. 4 and 5. [Nos. 6556, 6557, and 6558.]

Footbones.— There is a large series of footbones, the position of most of which it is impossible to determine. They are all well formed, with good articular surfaces, showing that the carpus and tarsus was fairly strong and well knit. Some of the more common bones of indefinite position are shown in Plate V, Figs. 18, *a* and *b*; 19, *a* and *b*; 20, *a* and *b*. [No. 6559.]

Astragali.— There seem to be two forms of astragalus. The first is much the more slender and smaller. There are two distinct facets for articulation with the calcaneum; the upper of these is the largest and is separated from the lower by a notch which, in combination with a similar notch separating the two articular faces on the calcaneum, forms a foramen between the bones. On the opposite side of the bone there is a large face set at an angle with the body of the bone, apparently for the tibia. The lower rim of the bone between the described regions has a narrow face for the bones of the tarsus. This ilium was ascribed by Cope to *clepsydrops colletii.* The form of the bone is shown in Plate IV, Fig. 7, *a*, *b*, *c*, *d*. [No. 6560.]

The second type is of stouter proportions than the first and larger; the articular faces are arranged much the same, but are broader and the face for the distal end of the tibia is more sharply divided into faces meeting at a considerable angle. Plate IV, Fig. 8, *a* and *b*. [No. 6561.]

Neither of these forms corresponds with the figure of the astragalus of *Clepsydrops leptocephalus*, published by Cope (Proc. Am. Phil. Soc., Aug. 1884; Am. Assoc. Ad. Sc. Vol. XXXIII, 1884), nor to an astragalus of *Pariotichus incisivus* in the collection of the Walker Museum.

The strong angulation of the tibial face is described by Cope as belonging to the genus *Dimetrodon*, so that it is possible that the larger astragalus in the Illinois material may represent that genus.

Calcanea.— The calcanea are of the type characteristic of most of the Permian reptiles from America. Large, subround disks of no great thickness; the side toward the astragalus presents two facets separated by a notch; above and below are facets for the fibula (?) and the tarsal bones. Plate IV, Fig. 9, *a* and *b*. [No. 6562.]

Metacarpals and Tarsals.— The metacarpals and tarsals are long and slender, with well developed articular faces. Plate V, Figs. 1 and 2. [No. 6563.]

Phalanges.— The phalanges show the same well developed form as the preceding row, even to the terminal series. The terminal series are slender, pointed, and curved, and evidently supported strong claws. Plate V, Figs. 3–9, and 10, *a* and *b*. [Nos. 6564 and 6565.]

Among the specimens that cannot be referred with certainty to any form are the following:

Teeth.—There are several isolated teeth or portions of jaws with teeth attached, which cannot be assigned to any of the described forms. It is probable that if more complete material were at hand they would be found to belong to forms already described, either from Illinois or Texas.

"*Species one*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

This is an incomplete maxillary with six broken teeth. "They stand in close juxtaposition and are of equal size. The basal half or more of the crown displays the character of deep inflections or grooves. These teeth belong to some sauroid fish or batrachian." Plate V, Fig. 12. [No. 6566.]

"*Species two*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

A fragment of a mandibular ramus with four teeth. "The anterior of these is larger and is separated from the others by an edentulous space. Their crowns are rather elongate and are compressed, having cutting edges fore and aft. Both edges contract to the apex, but the anterior the more so. There are a few shallow grooves at the base, but they appear to be superficial only." As remarked by Cope, it is impossible to tell whether they belong to an amphibian or a reptile. Plate V, Fig. 11. [No. 6567.]

"*Species three*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

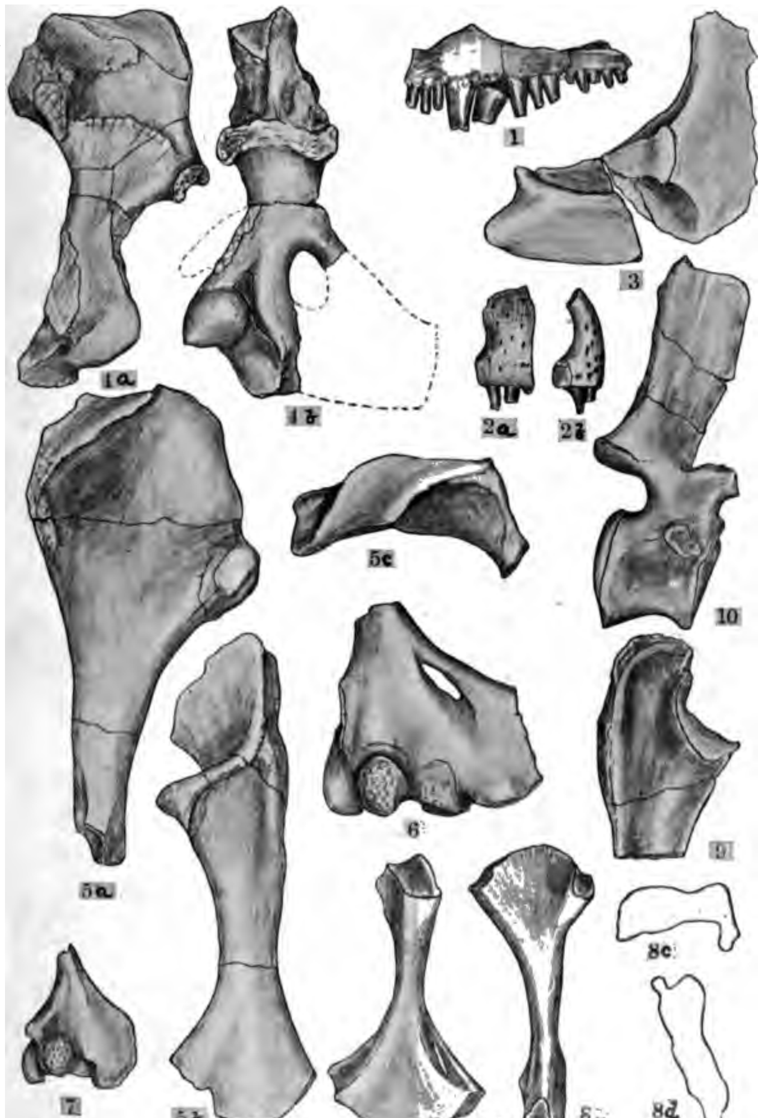
"Two stout, slightly flattened, conic teeth, without cutting edges, represent this species. They are anchylosed to a very thin plate of bone, a part of which adheres to each. The base is oblique, expanding more in one direction than in another. The greater part of the crown is marked by closely placed parallel grooves, which are more numerous than in the species No. 1. They are larger than those of No. 2, measuring .004^m in diameter at the base. They may belong to any one of a number of known genera of batrachia or sauroid fishes." [No. 6568.]

Besides these, there are two teeth that seem to indicate forms not otherwise represented in the collection. The first is rather conical and recurved, the upper end truncate, but the inner side shows a concave region of wear against the opposed tooth. This would seem to show that it is either an incisor or one of the lateral teeth, probably the first, of some member of the *Diadectidæ*. Plate V, Fig. 23, *a* and *b*. [No. 6569.]

The second is a very stout, conical tooth, much larger than any other in the collection. Its surface is marked with deep, irregularly arranged grooves. Plate V, Fig. 24. [No. 6570.]

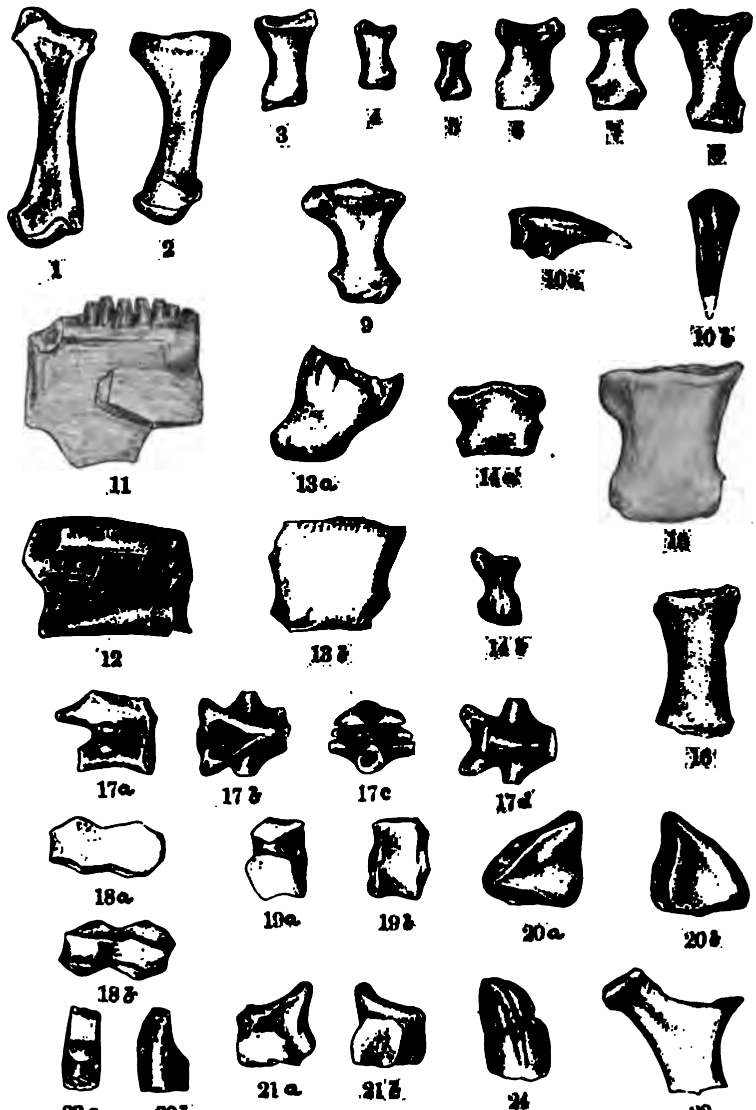
A lower jaw, nearly complete, resembles very closely that of *Pariotichus* from Texas. The articular region is complete and shows a well formed face and a prominent spur extending posterior to the cotylus. Fragments of other jaws show the same feature. The outer side is marked by strong reticulate sculpture, which at the posterior part seems to radiate from a point on

JOUR. GEOL., Vol. VIII, No. 8 Plate III



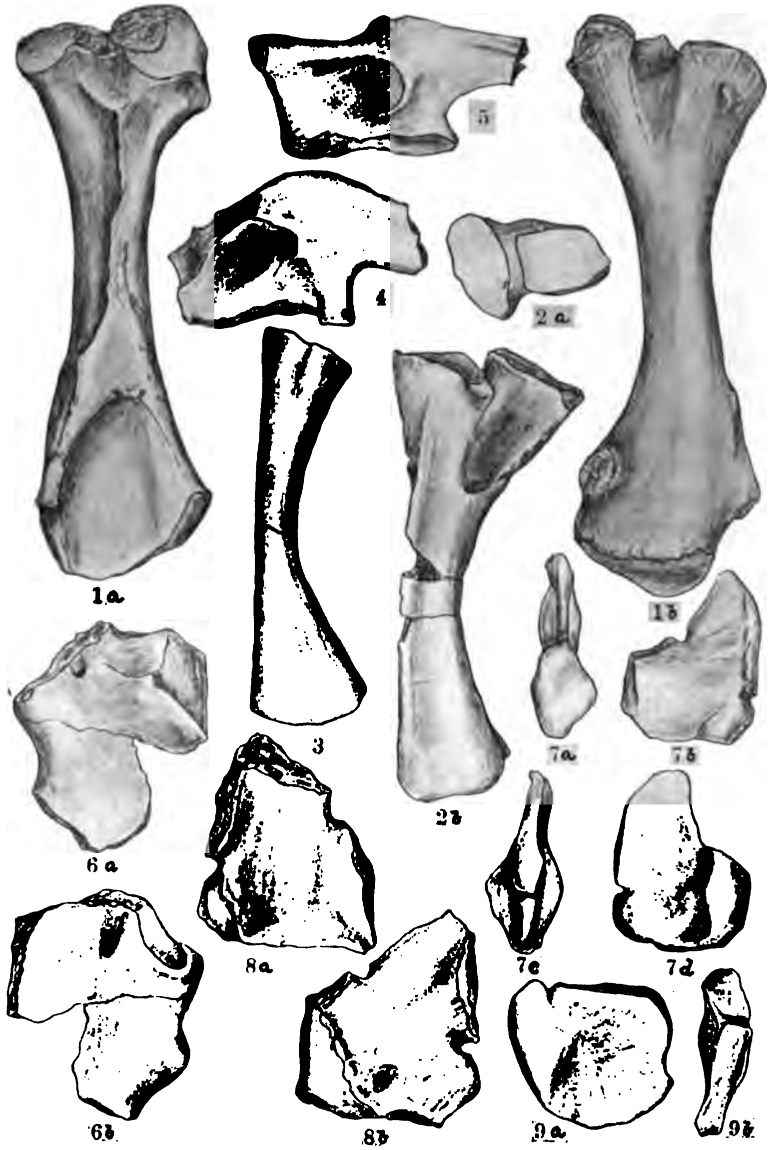
Permian vertebrates.

JOUR. GEOL., Vol. VIII, No. 8 Plate V



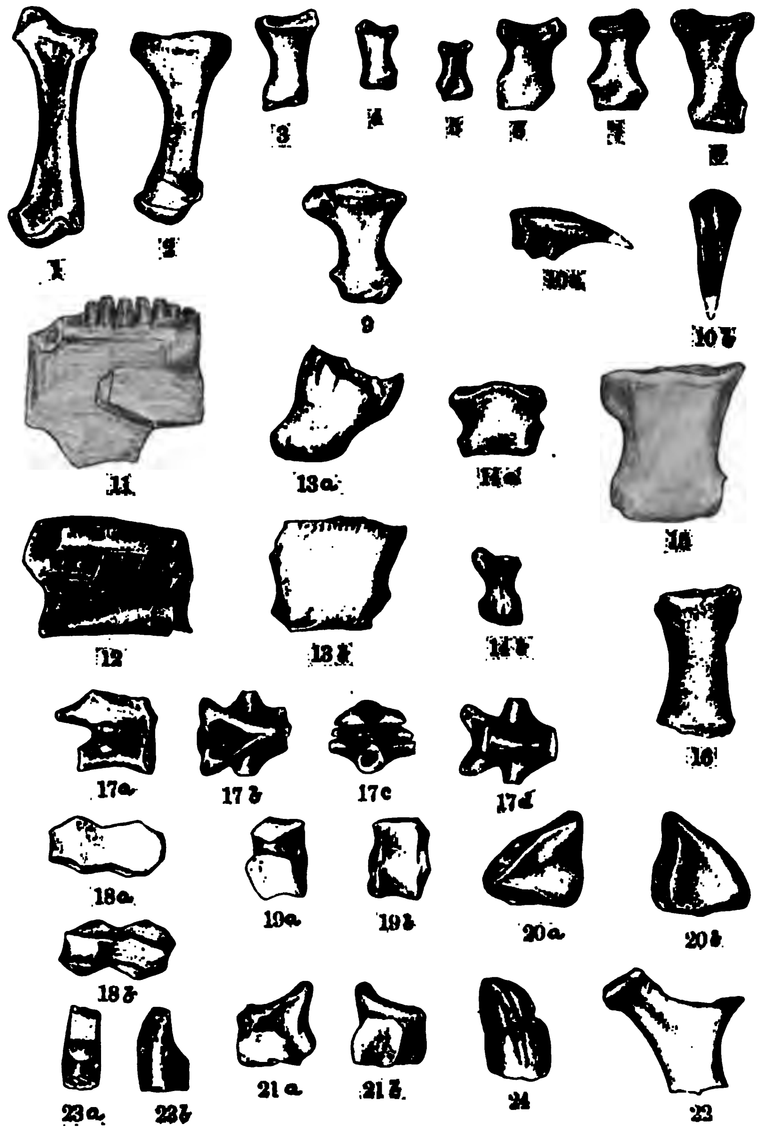
Permian vertebrates.

JOUR. GEOL., Vol. VIII, No. 8 Plate IV



Permian vertebrates.

Jour. Geol., Vol. VIII, No. 8 Plate V



Permian vertebrates.

FIG. 12. *Cricotus heteroclitus.* Intercentrum. *a*) from above, *b*) from before, *c*) from the side, *d*) from below.

FIG. 13. *C. heteroclitus.* Intercentrum.

FIG. 14. *C. heteroclitus.* Intercentrum.

FIG. 15. *C. gibsonii.* Intercentrum.

FIG. 16. *Diplocaulus salamandroides* Dorsal vertebra. *a*) from the side, *b*) from below. Twice nat. size.

FIG. 17. *D. salamandroides.* Dorsal vertebra. *a*) from above, *b*) from below. Twice nat. size.

PLATE II.

FIG. 1. *Clepsydrops collettii.* Dorsal vertebra. *a*) anterior, *b*) lateral, *c*) posterior.

FIG. 2. *C. collettii.* Dorsal vertebra. *a*) lateral, *b*) inferior.

FIG. 3. *C. collettii.* Dorsal vertebra. *a*) lateral, *b*) showing vertebra divided on median line.

FIG. 4. (?) *C. collettii.* *a*) inferior, *b*) lateral, *c*) anterior, *d*) posterior.

FIG. 5. *C. pedunculatus.* Anterior caudal. *a*) lateral, *b*) anterior, *c*) posterior, *d*) inferior.

FIG. 6. *C. sp.* Dorsal vertebra. *a*) lateral, *b*) posterior, *c*) anterior.

FIG. 7. *C. vinslovii.* Dorsal vertebræ. *a*) lateral, *b*) posterior, *c*) anterior, *d*) inferior.

FIG. 8. *C. sp.* Caudal vertebra. *a*) lateral, *b*) anterior, *c*) inferior, *d*) posterior.

FIG. 9. *C. sp.* Caudal vertebra. *a*) lateral, *b*) inferior.

FIG. 10. *C. sp.* Caudal verebra, lateral.

FIG. 11. *C. sp.* Axis. *a*) anterior, *b*) lateral, *c*) inferior.

FIG. 12. *Lysorophus tricarinatus.* Dorsal (?) vertebræ. *a*) from the side, *b*) from above, *c*) from below.

FIG. 13. *L. sp.* Dorsal (?) vertebræ. *a*) from above, *b*) from the side, *c*) from below.

PLATE III.

FIG. 1. *Archeobolus vellicatus.* Maxillary.

FIG. 2. Premaxillary. *a*) from before, *b*) from the side.

FIG. 3. Scapula and Coracoid.

FIG. 4. Humerus. [illegible] *a*) lateral view, *b*) posterior view.

FIG. 5. Humerus. *a*) anterior, *b*) proximal end, *c*) lateral. half nat. size.

FIG. 6. Humerus. Distal end of same form as 5.

FIG. 7. Humerus. Distal end.

FIG. 8. Humerus. *a*) anterior view, *b*) lateral, *c*) and *d*) outlines of the proximal and distal faces in natural position.

FIG. 9. Proximal end of Ulna.

PLATE IV.

FIG. 1. Femur. *a*) anterior, *b*) posterior.

FIG. 2. Tibia. *a*) proximal end, *b*) anterior view.

FIG. 3. Fibula.

FIG. 4. Ilium.

FIG. 5. Another type of ilium.

FIG. 6. Pubis. *a*) inner view, *b*) outer view.

FIG. 7. Astragalus of *Clepsydrops sp.* *a*) tibial face, *b*) anterior (?) face, *c*) calcaneal face, *d*) posterior (?) face.

FIG. 8. Astragalus of *Clepsydrops sp.* *a*) anterior (?) face, *b*) posterior (?) face.

FIG. 9. Calcaneum. *b*) astragalus face.

PLATE V.

FIGS. 1 and 2. Metacarpals of *Clepsydrops.*

FIGS. 3–9. Phalanges of *Clepsydrops.*

FIG. 10. Terminal phalanx of *C.* *a*) lateral, *b*) superior views.

FIG. 11. "Species one."

FIG. 12. "Species two."

FIG. 13. Phalanges of *Cricotus.* *a*) lateral, *b*) anterior views.

FIG. 14. Phalanges of *Cricotus.* *a*) anterior, *b*) lateral views.

FIGS. 15 and 16. Phalanges of *Cricotus.*

FIG. 17. *Diplocaulus salamandroides.* Dorsal vertebra. *a*) lateral, *b*) superior, *c*) terminal, *d*) inferior views.

FIGS 18–21. Carpal bones.

FIG. 22. Proximal end of a rib

FIG. 23. Incisor tooth. *a*) anterior view, *b*) lateral.

FIG. 24. Tooth.

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SOME PRINCIPLES CONTROLLING THE DEPOSITION OF ORES*

I would hardly have ventured to talk on the subject of ore deposits to you if I had not approached the subject from a different point of view from the majority of men who have considered it. The point of view from which the subject of ore deposits has been most frequently considered has been that of a study of ore deposits themselves. A geologist or mining engineer has studied this or that ore deposit, or a number of ore deposits in different districts, and has then generalized concerning the ore deposits of other districts, and perhaps of the world. I also have considered the subject of ore deposits to some extent from that point of view, but if I had done this only, I would not have ventured to give a general address upon the subject.

[illegible] the question of the alterations of [illegible] processes. In treating [illegible] necessary for me to consider somewhat [illegible] the principles which control its flow [illegible] the results which it accom- [illegible] reached certain conclusions upon that [illegible] the deposition of most ores was a [illegible] the general principles controlling the [illegible] Therefore it is from the point of [illegible] underground water that I wish [illegible] to-night. However, I can- [illegible] to refer to my more [illegible]

* [illegible] Engineers at [illegible] XXX [illegible]

extended paper found in Vol. XXX of the *Transactions of the American Institute of Mining Engineers.*

There are three great classes of ore deposits; (1) those which are produced by igneous processes; (2) those which are produced by the direct processes of sedimentation; (3) those which are produced by the work of underground water. The last class is by far the largest, and it is the only one which I shall consider this evening.

My first, then, and my fundamental premise is, *That the most important class of ore deposits is the result of the work of underground water.* This premise I shall not attempt to prove; but because it is accepted by most geologists and by most mining engineers shall use it as a starting point.

My second fundamental premise is, *Ore deposits are derived from the outer crust of the earth, from that part of the crust of the earth which I have called the zone of fracture.*[1] There has been much discussion as to whether ore deposits are produced by descending waters, lateral-moving waters, or ascending waters. One of the most comprehensive papers which has been presented upon this subject was by Posepny.[2] In this paper Posepny holds that the original source of the metals of practically all the ore deposits of the class produced by underground water is the Barysphere (heavy-sphere), and therefore that the metals come from very far below the surface of the earth. The water in some mysterious way came from this heavy sphere, presumably very deep seated. The water rising from the Barysphere, where the rocks are supposed by some to contain more metalliferous material than near the surface, brought the metals of the ore deposits to their present positions. This view has been presented at great length by Posepny, ably argued, and he has had many disciples. Now it seems to me that the well-established principles of physics absolutely disprove this

[1] Principles of North American pre-Cambrian Geology, by C. R. VAN HISE: Sixteenth Ann. Rept. U. S. Geol. Surv., 1894–5, Pt. I, p. 589.

[2] The Genesis of the Ore Deposits, by F. POSEPNY: Trans. Am. Inst. Min. Engineers, Vol. XXIII, 1894, pp. 197–369.

hypothesis; and it further seems to me that observed geological phenomena also disprove it.

I have elsewhere divided the outer crust of the earth into zones, in descending order as follows: a zone of fracture, a zone of combined fracture and flowage, and a zone of flowage.[1]

Now, we will suppose that the crushing strength of the strongest rock is such that at a depth of twenty thousand meters below the surface the weight of the superincumbent rock (less the floating effect of underground water) is as great as the crushing strength of the rock. We will suppose that such a rock as the Berlin granite of Wisconsin, the strongest rock yet tested, having a crushing strength of 47,674 pounds per square inch,[2] extends from the surface to an indefinite depth. We will further suppose that in some way openings of some kind, say large cracks, are produced at the depth where the rock is under weight as great as its crushing strength. What would happen? You engineers know very well the rock would be crushed and the openings would close. Therefore at a depth of more than 20,000 meters below the surface of the earth, where the weight of the superincumbent rock is greater than the strongest rocks, if it be supposed that cracks of a considerable size could be formed, the pressure would crush the rocks and close the cracks. But the crushing strength of the great majority of the strong rocks does not exceed one half that of the Berlin granite. Moreover rocks at considerable depth are at higher temperatures than normal, and this probably weakens them. Consequently upon physical grounds we are prohibited from supposing that there are cracks and crevices of considerable size at more than a very moderate distance below the surface of the earth. But this conclusion does not rest upon physical principles alone. I have shown that there is another way besides crushing by which

[1] Principles of North American pre-Cambrian Geology, by C. R. VAN HISE: Sixteenth Ann. Rept. U. S. Geol. Surv., 1894–5, Pt. I, p. 589.

[2] Building and Ornamental Stones of Wisconsin, by E. R. BUCKLEY: Bull. Wis. Geol. and Nat. Hist. Surv., No. 4, 1898, p. 390.

rocks are readjusted to deforming stresses.[1] If the movement be slow and the temperature that of moderate depth the stress does not need to accumulate so that it shall be greater than the crushing strength of the rocks. Under such conditions, long before the crushing strength is reached, the contained water begins to act upon the material of the rocks and re-arranges it by continuous solution and deposition; so that it behaves as a plastic body. At all times the rock is a solid except for the infinitesimal amount held in solution; and yet it continually adjusts itself to the deforming stresses. A great many rocks which have been thus deformed under deep-seated conditions have a laminar structure which is analogous, not exactly similar, but analogous, to the leaves of a book. To make the analogy exact it would be necessary to suppose that the leaves are welded together, *i. e.*, held firmly by the molecular attractions between them. What has happened in the case of these laminar rocks? They have been transformed from a massive to a laminated form by recrystallization, but in many cases combined with mineral granulation and differential movements of the mineral particles. During the process of recrystallization, for each mineral particle, material is continually taken into solution on the sides where subjected to greatest stress and deposited on the edges where the stress is less, until the laminar structure is produced. The process of adjustment largely and in many instances mainly by continual solution and redeposition is rock flowage. Now rocks in which this process has taken place are found at the surface at many places. Moreover these rocks are frequently those of great strength. In many places it is certain that the amount of material which has been removed by erosion since the rocks were recrystallized is not more than 2000 or at most 3000 meters. Since, therefore, the process of rock flowage often takes place at much less depth than that at which rocks are crushed, it follows that large openings are not likely to exist at depths so great as above calculated for the closing of openings

[1] Metamorphism of Rocks and Rock Flowage, by C. R. VAN HISE: Bull. Geol. Soc. Am., Vol. IX, pp. 269–328, Pl. XIX.

by crushing. It is highly probable that few openings of appreciable magnitude exist at depths so great as 10,000 meters.

Therefore from the principles of physics and from observation we conclude that crevices and cracks of considerable magnitude do not exist below a very moderate depth. I would not say that minute cavities filled with liquid do not exist in the zone of rock flowage. I would not say that very small openings filled with gases may not exist in that zone; but there is every reason to believe that such cavities are exceedingly small. And it is well known that ore deposits in order to be of economic value must be of considerable magnitude. Such deposits were not formed in the minute and discontinuous openings filled with gas or liquid which very possibly exist at great depth.

But let us now consider this subject from another point of view. You as engineers know very well that the friction of a moving liquid increases very rapidly as the size of the passage through which it moves decreases. This is true even of super-capillary tubes. It is still more true of capillary openings, and the [illegible]

impossible in the deep-seated zone in which there are no continuous cracks and crevices of considerable size; hence the hypothesis of the derivation of the metals of the ores from the Barysphere is untenable. Valuable ore bodies have been deposited in openings and passages of considerable size and by a vigorous underground circulation. Since the magnitude of openings and vigorous circulation are correlative with, and exist only in the upper zone, that of fracture, the ores must have been derived from and deposited in this upper part of the crust of the earth.

If, then, we admit the fundamental premise, that the majority of ore deposits are the work of underground water, it seems to me that the conclusion cannot be escaped that the metals which are in the ore deposits are immediately derived from an upper zone, probably having a maximum depth of 10,000 meters, or seven or eight miles, in which the circulating waters are vigorous and effective.

However, I do not assert that now, or at any time in the past, metals for ores have not been derived ultimately from a deeper source through the agency of vulcanism, the medium of transfer being the igneous rocks. We do not know how deep down the igneous rocks which are intruded into the zone of fracture or flow out at the surface of the earth are transformed to magma, if they have not always existed as magma. We do not know very well the process by which the igneous rocks make their way up through the solid rocks of the zone of flowage. We do know, however, that they come from a very considerable depth, and take advantage of openings and cracks and crevices as soon as they reach the zone of fracture. For instance, in the Sierra Nevada, where there are various great sets of joints in the granite — vertical, inclined, and horizontal — the lava coming up from below has wedged itself into these joints, producing sets of parallel dikes. As these joints are utilized by the igneous rocks, so are openings of other kinds where igneous rocks intrude the zone of fracture. Igneous rocks in vast quantities as lava are poured out on the surface or as tuff fall upon it.

into the sandstone below you know that great quantities of water issue. The water falls upon the ground far to the northwest in central Wisconsin, where the sandstone reaches the surface. It follows this pervious formation below impervious strata, and when the impervious strata are punctured at Chicago rises to the surface through the opening. So it is with artesian wells everywhere. I repeat, *The waters which we know to be vigorously circulating are of meteoric origin, and these are the waters which have deposited the ores.*

We are now ready to pass to the fourth of my premises, viz., *The movement of underground water is mainly due to gravitative stress.* This is perhaps so plain to you as engineers that it will hardly need proving; but certainly many men who have written about ore deposits have given other explanations. Why does the water rise in the artesian wells in Chicago? Simply because the level of underground water at the northwest where the sandstone is fed is at a higher elevation. The difference in elevation is only a few hundred feet; and yet the difference in the weight of the columns, or the force of gravity, is sufficient to drive the water underground through the sandstone for a hundred or more miles to Chicago and make it rise considerably above the level of Lake Michigan. If the deformation had been such that the porous formation had somewhere been depressed nearly to the bottom of the zone of fracture, and the openings did not thereby become smaller, this in no way would have lessened the speed of circulation. It is therefore clear from our knowledge of artesian wells that a very moderate head is entirely adequate to account for an underground lateral circulation of great length and for a vertical circulation of great depth — entirely adequate to account for it. If this be true, why should we appeal to subterranean heat or to the unknown mysterious forces at the depths as a main cause for underground circulation?

I do not deny that in some cases water is squeezed out of the rocks by orogenic movements, nor do I deny that heat produces an effect in underground circulation. We may suppose,

for instance, that the water entering at one point issues at another point at the same elevation, after following a deep underground path. Suppose the water during the journey comes in contact with volcanic rocks, or suppose the water becomes warmer as the result of the normal increase in temperature with increased depth. We will suppose, for the sake of simplicity, that the temperature of the water is 0° C. where it enters the ground, and at a temperature of 100° C. where it issues. This is an extreme case, and beyond the facts; but it makes the illustration simple. During its journey the water expands as a result of its rise in temperature, and a unit volume of the issuing water weighs only about 96 per cent. as much as does a unit volume the entering water. The cooler or descending column contains a greater mass of water than the ascending column; it is, therefore, pulled stronger by the force of gravity; and consequently circulation takes place. The descending column falls and the ascending column rises because of the gravitative stress.

In the case of the Chicago artesian wells we have seen that the flowage is due to differential gravitative stress resulting from difference in elevation. In the case we have just considered, we have seen that the flowage is due to differential gravitative stress occasioned by difference in temperature. Therefore, underground water circulation caused by gravitative stress may be initiated by difference in head or difference in temperature, or by both combined. Ordinarily difference in head and difference in temperature work together. Commonly water enters the ground at a higher level than it issues; and I think it can be shown that water which is descending is, upon the average, at a lower temperature than water which is ascending, although I cannot stop to fully discuss this point. Therefore the descending column is heavier. Hence, unequal gravitative stress, caused by difference in head and by difference in temperature, is the adequate cause to which I appeal to account for the circulation of underground water which does multifarious kinds of geological work, a small part of which is the deposition of ores.

It is now necessary to consider in some detail the manner in which underground water moves. For a long time I have realized that if underground water had a difference in head that it might penetrate to a great depth and rise again to the surface;

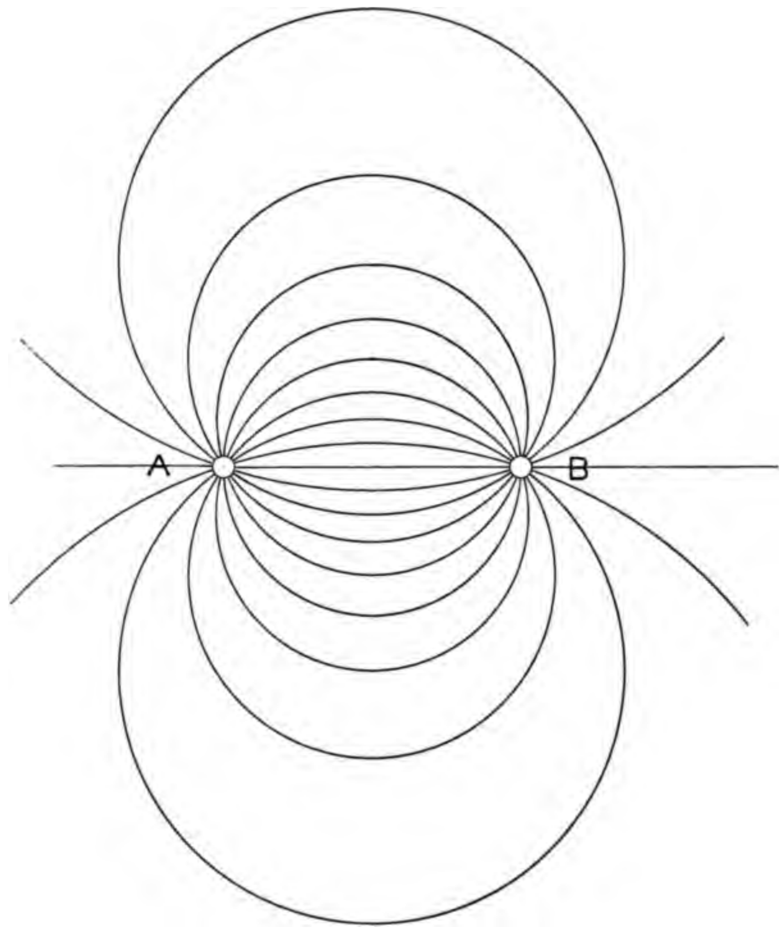

FIG. 1.

but I did not realize that it was not necessary to assume exceptional openings for such a circulation. I assumed that where such a circulation took place exceptionally favorable channels were available; but a recent paper by Professor Slichter[1]

[1] Theoretical Investigation of the Motion of Groundwaters, by C. S. SLICHTER, Nineteenth Ann. Rept. U. S. Geol. Surv., 1899, Pt. II, pp. 295–384.

upon the motion of groundwaters showed me that this was an entirely unnecessary assumption, and gave me the additional data needed upon this point. This chart (Fig. 1) is a horizontal diagram. A represents one well and B another well, separated by a homogenous porous medium. Into the well B, I pour water. In the well A there is no water at the outset; and the water flows from the well B to the well A through the medium. What is the path of the water? Its flowage is represented by the curved lines. Some of the water goes in a nearly direct course. Another part takes a somewhat curved course. Still other parts of the water follows a very indirect course, represented by the longer curved lines. All of the available cross section is utilized. If for instance this room were filled with water, and water were running in at one place in the front end of the room and were escaping at one place in the rear end of the room with equal speed, would the water simply follow the direct line between the two? You know perfectly well it would not. The entire available cross section of the room would be utilized, although the more direct course would be utilized to a greater extent than the more indirect course. This is intended to be illustrated on the chart (Fig. 1) by the lines representing the nearly direct courses being close together, and the lines representing the indirect courses being farther apart.

This chart (Fig. 1) then represents the horizontal circulation. If we pass to the vertical circulation the flowage is represented by this chart (Fig. 2). The water is being poured into the well B and passes to the well A. The water follows the course of the curved lines, so that with a difference in head equal to the difference in the level of the water in the two wells, a considerable part of the water being poured into B and passing through the homogenous porous medium to A penetrates a considerable depth, from which it rises and enters the well A. Now what will be the limit in nature of the downward search of underground water? We have already given it. Manifestly the lowest limit of effective circulation at any place is the bottom of the zone of fracture at that place. The zone of flowage

below is practically impervious. However, an impervious limiting stratum may exist at depths far less than the bottom of the zone of fracture. An impervious limiting stratum, perhaps a shale, may be found at a depth of 100 meters or less, or at any

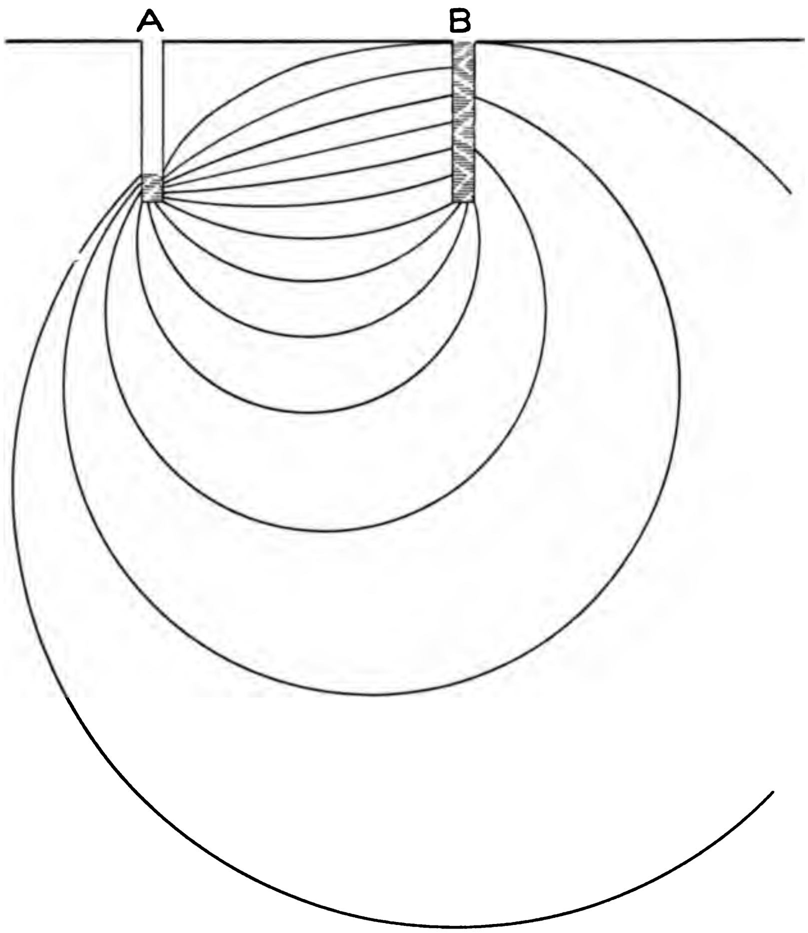

FIG. 2.

depth intermediate between this and the bottom of the zone of fracture for the strongest rocks. Where there are one or more pervious strata which are inclined and above, below, and between which are impervious formations, there may be two or more

nearly independent circulations. To illustrate, at Chicago the St. Peter's sandstone, the Potsdam sandstone, and even different parts of the Potsdam sandstone have more or less independent circulations. If a limiting stratum be supposed to be half-way down on the chart (Fig. 2) the lines of flow above this stratum would not be as they are now, but would be flatter and would be limited by the impervious rock.

Under natural conditions wherever there is an impervious rock there is a limit of some particular circulation in that direction. A limiting stratum may therefore be very near the surface, at the bottom of the zone of fracture, or at any intermediate depth; and theoretically a moderate head is sufficient to do the work of driving the water to any of these depths. Indeed, there is no escape from the conclusion that at least some circulation does occur in the deeper parts of the zone of fracture with a very moderate head. Of course in proportion as the head is great the circulation at depth is likely to be vigorous. But it may be objected that a deep circulation, while theoretically possible, must be exceedingly small in quantity, and consequently of comparatively little account in the deposition of ores. But the consideration of the underground circulation in reference to the Chicago artesian wells, shows that this objection has little weight. (See p. 737.) Moreover, the deeply circulating water, if less in quantity than that near the surface, takes a longer journey and is longer in contact with the rocks through which it is searching for the metals. Not only so, but it is at a higher temperature than the water at higher levels; and this also is favorable to taking mineral material in solution. And, finally, because it has a higher temperature it has less viscosity. While the variable viscosity of water is not so very important in reference to circulation in super-capillary tubes, in capillary tubes, which constitute a very large fraction of underground openings, and especially those at considerable depth, the viscosity is important —the flowage increasing directly as the viscosity decreases. The viscosity of water at 90° C. is only one fifth as much as it is at 0° C.; and therefore with a given head of water in capillary

tubes, if the temperature be considerably increased—and but a moderate depth is required to give considerable increase—the water moves several times as fast as it would at the surface under conditions similar in all respects save temperature. Therefore, because of these three factors, long journey, high temperature, and low viscosity, we cannot exclude the deep circulation from consideration. This circulation is indeed believed to be very important in the deposition of ores.

We are now prepared to consider the actual journey of underground water. Where water falls upon porous ground it finds innumerable openings through which it enters and begins its underground journey. This circulating water, as far as practicable, under the law of the minimum expenditure of energy, follows the paths of easiest resistance. But these are the larger openings, because resistance due to friction along the walls and within the current is very much less per unit circulation in large than in small openings. While therefore water enters the ground at innumerable small openings, as it goes down it more and more seeks the larger openings. Once found, it holds to them. The farther it continues its journey, the greater the proportion of the water which follows the larger openings. But if this be true, the water in its descending course is more likely to be widely dispersed and in the smaller openings; and in its upward course more likely to be concentrated and in the larger openings.

We can now follow the course of underground water in detail, but in doing this it is necessary to consider the elements of the problem separately. It is only by passing from a simple case to the very complex one of nature that we can understand the latter. Here is a chart (Fig. 3) which shows the surface of a slope, the level of groundwater, and the flowage of water in the simplest imaginable case. Below the level of groundwater all the openings in the rocks, great and small, are filled with water. The rocks are saturated. In the case represented I have supposed that all of the water enters at a single point, A; and that all of it issues at a single point, B. The curved lines represent the

flowage of the water through a homogeneous porous medium. In the next chart (Fig. 4) I have supposed water to enter at three points and issue at one; and I have supposed the flowage from each point of entrance to occur just as if no water were

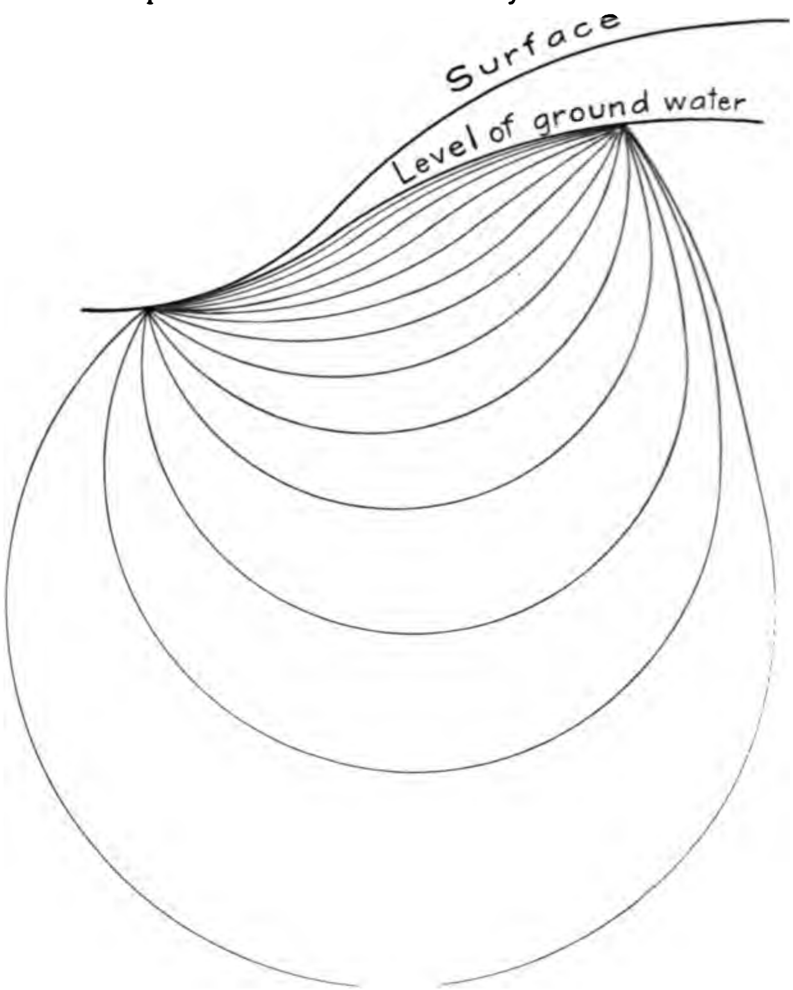

FIG. 3.

entering anywhere else, and therefore the systems of flowage to be superimposed. Of course this is not a real case. Underground water does not diverge from a single point and converge at another point in independence of the water entering

at other points. The water entering at innumerable points in vertical section and in horizontal section mutually interfere, and make the course for any given particle of water rather simple.

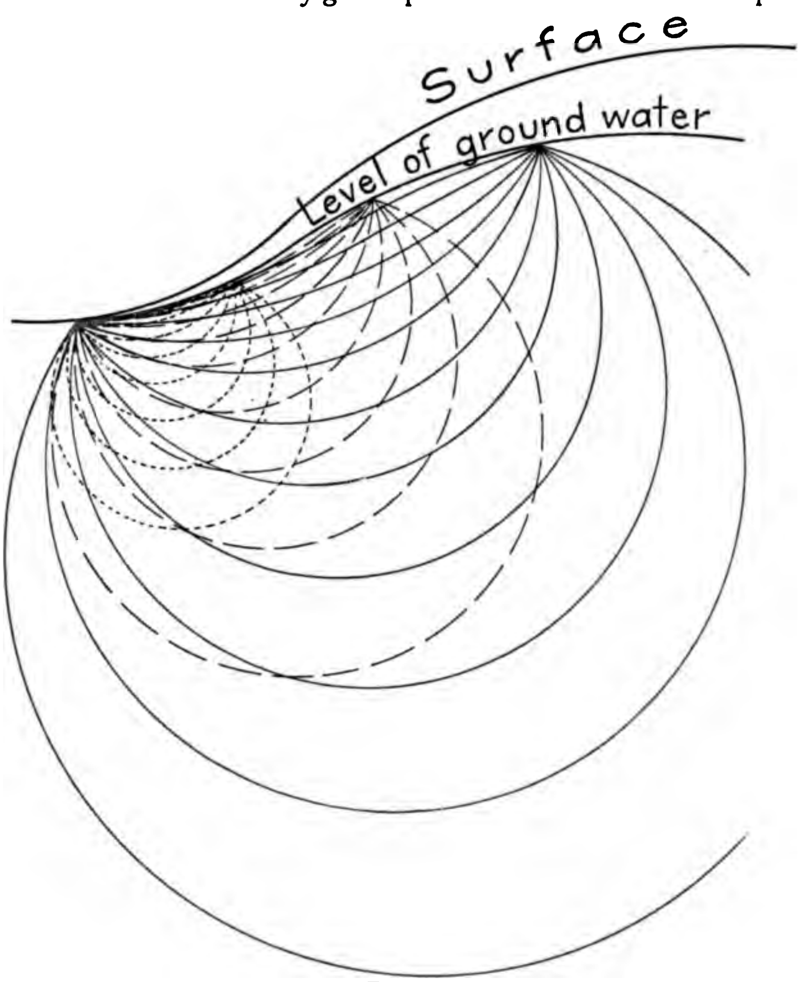

FIG. 4.

This I have tried to represent by another chart (Fig. 5). In this chart I have supposed particles of water to enter at equal horizontal intervals, and issue at a single point. You note that the water near the crest begins its journey by almost vertical

descent. In proportion as the entering water is near the valley the horizontal component becomes more important. The water near the valley follows a comparatively shallow course; but this water uses all the available space near the surface, and conse-

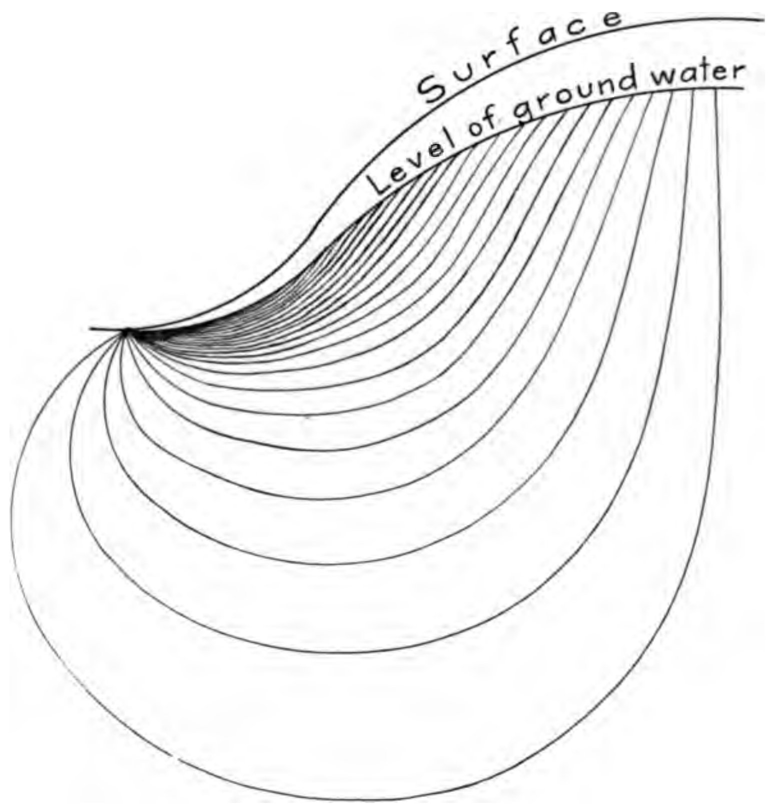

FIG. 5.

quently the water entering at the higher ground necessarily follows a long, circuitous, and deep course. The chart (Fig. 5) therefore represents the flowage with many points of entrance and a single point of exit, where there is interference of the circulating waters.

Thus far it has been supposed that the ground is uniformly porous, like an evenly grained sandstone without joint or fracture

of any kind, in which the water can go in all directions with equal ease. But absolute uniformity does not exist in nature. The openings in rocks are never of uniform size; they are never equally distributed. Suppose half way down the slope

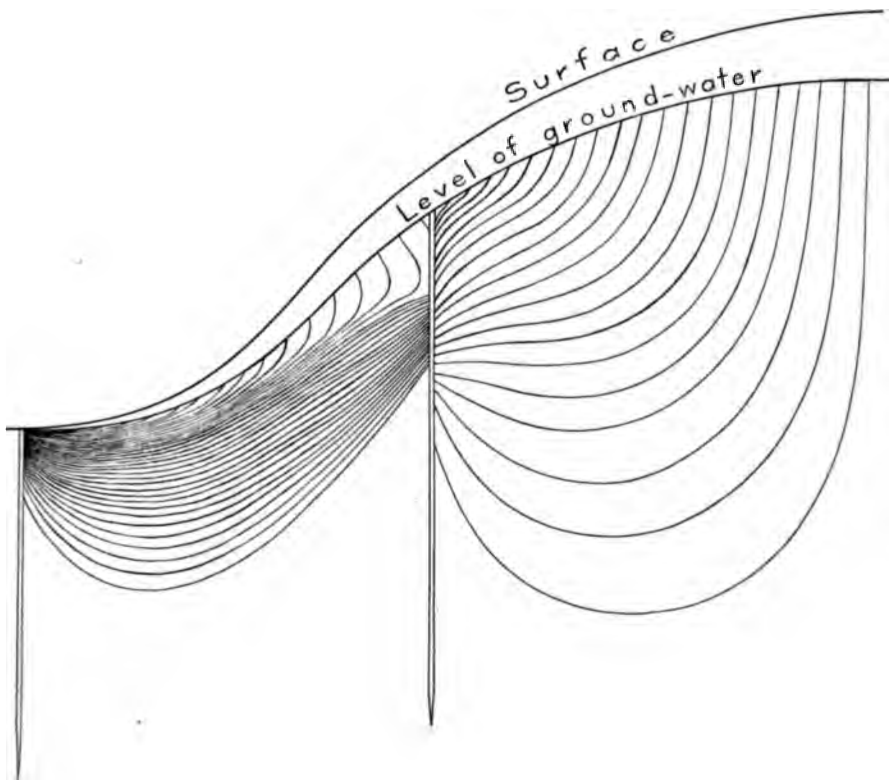

FIG. 6.

there is a vertical opening of unusual size transverse to the plane of the chart (Fig. 6), and another similar opening below the valley. If you please, we will call them fissures. These fissures, because large openings, will be fully utilized by the underground water. We readily see that groundwater will enter the higher fissure at many points and from various directions. Ordinarily it will enter the upper part while it is still descending; it will

enter the central part laterally; it will have begun its ascent before it enters the lower part. Therefore a fissure upon the middle of a slope will be very likely to receive water from above, from the side, and from below. But at a certain area of a fissure well up on the slope the water continuously received at the upper side of the fissure will escape laterally at the lower side. This water and that entering the ground below the upper fissure will make its way to the fissure below the valley. But here the level of groundwater is at the surface. Consequently all the water entering this fissure will ascend quite to the surface, and issue as a spring. If there be a fissure at the crest we can see that the descending water will go a long way down; but the waters will nowhere be ascending. If there be a fissure on the slope, both descending and ascending waters will ordinarily be active; although it is of course recognized that in fissures thus located the conditions may be such that the waters will ascend or descend only. If there be a fissure below a valley where the level of groundwater is at the surface the water will all be ascending; and there will be no descending water. At such places we have springs. Springs do not issue from the tops of mountains, but from slopes and valleys, most frequently the latter. Illustrating this are the Yellowstone Park springs of the Firehole River. The waters which feed the springs fall upon the crests and slopes of the mountains adjacent; on their way to the valley go deep below the surface, and at the Firehole ascend as hot springs and geysers. The water is driven by gravity due to a considerable head and the lower temperature of the descending column.

You are all doubtless aware that three theories are maintained as to the source of the waters which deposit ores. Some hold that the waters doing the work are descending; others that they enter laterally; others that they are ascending. The first is known as the descension, the second as the lateral secretion, and the third as the ascension theory. If my argument be correct as to a limit to the zone of fracture, fissures, as well as all other openings, must gradually become smaller and smaller.

and finally die out altogether. Water in a fissure may descend or may ascend for a considerable distance; but it is perfectly clear that, so far as fissures are concerned, except for the small amount entering the surface openings, the water must enter laterally. Consequently, if we apply the lateral-secretion theory broadly enough, we may say that all the waters which feed the fissures are lateral-secreting waters. But if we are descensionists, and consider only the upper part of a fissure on the slope—and that is what many very naturally have done because this is the part of the fissure most easily observed—we may say that the waters which are doing the work are descending waters. Or, if we are in such a district as that of the Comstock lode, in which are found great volumes of ascending water, we may say that the waters which are depositing the ores are ascending. All may be true. But in the past Sandberger held that lateral-secreting waters in the narrowest sense did all the work, and he refused to believe that ascending and descending waters were of importance; and Posepny held that ascending waters did nearly all the work, and gave small consideration to lateral-secreting and descending waters; whereas you see with perfect clearness that each theory is incomplete. Both are needed; they supplement each other.

Passing now to the work of underground water, we find there are very great differences in the nature of the work which takes place above the level of groundwater and below the level of groundwater. The first is called the belt of weathering; the second the belt of cementation[1] (see Fig. 7). Also there are great differences in the work which takes place in the zone of fracture, which includes both the belts of weathering and cementation, and that in the deep-lying zone, that of rock flowage. All of these differences have a very close bearing upon some phase of ore deposition. But the subject is too complex for me to take up fully, and I shall simply give the major differences in the reactions without stopping to demonstrate their

[1] Metamorphism of Rocks and Rock Flowage, by C. R. VAN HISE: Bull. Geol. Soc. Am., Vol. IX, p. 278.

correctness.[1] Above the level of groundw
weathering, the chemical reactions of oxic
hydration, and solution are the rule. The me
disintegration, softening, and decomposition o
the level of groundwater, in the belt of ceme
ral reactions of oxidation and carbonation
hydration occurs very extensively. Instead
tion is continually taking place. The mechani
rocks, instead of being disintegrated, softene
are hardened, the openings being cemented.
material for cementation? Why, from this

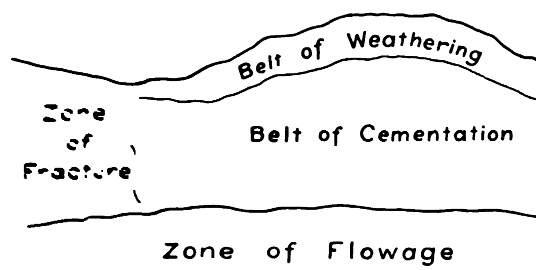

FIG. 7.

zone where solution is taking place. If th
of weathering are continuously taking mate
and are continuously depositing material b
goes on these belts steadily migrate down
of weathering not long ago geologically
cementation. While, therefore, the belt of
given time in the past, as now, was relativel
moved downward for thousands of feet. In
it is estimated that from 1000 to 3000
rock have been removed from above the pr
of this thickness has been in the belt of we
at any one time the belt of weathering ma
score or few score meters in thickness. Ther
of weathering a great and adequate amoun

[1] For a fuller discussion see Metamorphism, cit., pp. 27

have been derived to fill the cracks and crevices of the entire belt of cementation below, although this belt may be thousands of meters thick. This process of filling cracks and crevices by deposition is the general law for the great belt of cementation below the level of groundwater, just as certainly as solution is the general law for the belt of weathering above the level of groundwater. These are the dominant processes. However, I by no means assert that deposition does not occur in the belt of weathering, and that solution does not occur in the belt of cementation. Indeed, the solution of material in various places, in both the belts of weathering and cementation, and the deposition of this same material or a part of it in the same belts at other places are very important processes.

We therefore conclude that the solution of material in the belt of weathering and the deposition of material in the belt of cementation, and the solution and deposition of material within the same belts, fills the openings in the rocks below the level of groundwater. These processes are gradually changing the soft sandstones, such as exist below the surface limestone of Chicago, into quartzite. By the same processes fractures—small and great, from minute joints to great fissures—are filled by deposition of material from underground waters. The formation of ore deposits is largely an incident of this process. The volume of material transported from the belt of weathering and deposited below in the openings of the belt of cementation, and transferred from place to place within these belts, is many million times greater than the ore deposits. The development of ores is merely an exceptional case of a widespread and most important geological process, the deposition of ores involving only a consideration of the particular materials which are of value to man. This evening I propose very briefly to discuss the source of such materials: how they are carried; why and where they are deposited. The particular case is under the general laws which control the general process of solution and deposition.

There are a great many chemical laws which affect the process of ore deposition, and a few of them I am obliged to

mention. The first law is: All the elements and compounds of nature are soluble to some extent in water. If water be placed in contact with an hundred substances, it will hold some part of every one of those substances in solution. It follows that if, in the journey of underground water, it finds here and there gold or silver or lead or zinc or iron, in quantity small or great, those materials to some extent will be taken into solution. The second law is the fundamental principle of chemical dynamics, viz.; Chemical action is proportional to the active mass. To illustrate, other things being equal, the greater the quantity of a compound present, the greater the quantity which will be taken into solution and deposited from solution.

The materials will be likely to be taken into solution in large measure during the descending course of the water; and deposited from solution in large measure during the ascending course of the water. For this there are a number of reasons. First, solution is likely to occur during descension because the conditions are those of increasing temperature and pressure. It is well known that increase of temperature greatly increases the solvent power of water. In many cases a slight rise in temperature is sufficient to increase this activity in an amazing degree; in fact out of all proportion to the increase of temperature. Deposition is likely to occur during ascension because the conditions are those of decreasing temperature and pressure.[1] Second, some substances are held in solution better than others. Certain substances, such as quartz, may be deposited during the downward course of the water, and a more soluble substance, such as gold, silver, or some other substance, be dissolved at the same time. Third, the larger openings, such as fissures, are the trunk channels of water circulation. In them the waters from different sources mingle; and this to my mind is the most important single factor—probably the dominant factor,

[1] The relations of temperature and pressure to solution and precipitation are much more complicated than implied in the above general statement. For a more nearly exact expression of the facts see Some Principles Controlling the Deposition of Ores, by C. R. VAN HISE: Separate from Trans. Am. Inst. Min. Engineers, Vol. XXX, 1900, pp. 38–43.

in the precipitation of ores. If the contents of half a dozen test tubes filled with solutions chosen at random be dumped together, a precipitate is almost sure to form. And just so sure as underground waters come from this source and that source and mingle in the trunk channels of underground circulation, just so surely are precipitates formed. Fourth, in the formation of an ore deposit the wall rock may contribute a solution which precipitates a metal, or it may contribute a metal which is precipitated by a solution. Consequently an ore deposit may be confined to a particular horizon where there is a certain rock. For instance, lead and zinc are very generally associated with limestone, and the sandstones or other rocks above or below are very likely to be deficient or nearly devoid of these metals. To a less extent other ores show a decided preference for limestone as compared with other rocks. The explanation may be that the limestone itself furnishes the material; and this is believed to be the fact in various cases. The explanation may be that the limestone furnishes a precipitating agent to solutions derived from other rocks. It may be that the limestone because of its ready solubility furnishes large openings in which big deposits may be formed. Finally the explanation may lie in the combination of two or more of these factors. I have no doubt if we consider the whole world each of these factors is important, and that in some cases all of them coöperate. As a result of the combination of the various factors above considered a porous rock or an opening once in a million or ten million times receives enough of the metallic materials in solution so that a fraction of an ounce of gold per ton, or a few ounces of silver per ton, or a few per cent. of copper or some other metal, or a large per cent. of iron, will be precipitated; and we call the material an ore deposit. An ore deposit it is from an economic point of view. From a geological point of view it is usually to a far greater extent quartz and calcite and other gangue minerals.

I wish now to go a little further and consider the fissure on the slope shown in this chart (Fig. 6), both in the past and the

appreciable."[1] This deep ore is mainly copper-bearing pyrites. Douglass tells us that in depth every copper deposit of the entire Appalachian region of the United States shows only cupriferous pyrrhotite. An excellent illustration is Ducktown, Tenn., where at the level of groundwater was a very rich deposit of chalcocite but a few feet thickness which rapidly changed into very low grade cupriferous pyrrhotite.[2] In Australia down to the level of groundwater are high values in native gold; below the level of groundwater are auriferous pyrites bearing relatively small values of the precious metals.[3] Some of the superintendents say where ounces of gold are found above the level of groundwater only pennyweights are found below.[4] In the Sierra Nevada of the United States, according to Lindgren,[5] above the level of groundwater the gold values ran from $80 up to $300 per ton; but below the level of groundwater where there are sulphurets the values average from $20 to $30 per ton. Notwithstanding the fact that occurrences such as those mentioned are typical of the ore deposits of many districts of the world it has been believed by very many practical mining men that ore deposits become richer upon the average with increase of depth; but it must be admitted that the facts do not justify this sanguine expectation. In fact nine mines out of ten, taking the world as a whole, are poorer the second 300 meters than they are the first 300 meters, and are poorer the third 300 meters than they are the second 300 meters. In fact, many

[1] The Ore Deposits of Butte City, by R. C. BROWN: Trans. Am. Inst. Min. Eng., Vol. XXIV, 1895, p. 556.

[2] The Persistence of Lodes in Depth, by W. P. BLAKE: Eng. Min. Jour., Vol. LV, 1893, p. 3.

The Ducktown Ore Deposits and Treatment of the Ducktown Copper Ore, by C. HENRICH: Trans. Am. Inst. Min. Eng., Vol. XXV, 1896, pp. 206–209.

[3] The Alterations of the Western Australian Ore Deposits, by H. C. HOOVER: Trans. Am. Inst. Min. Eng., Vol. XXVIII, 1899, pp. 762–764.

[4] The Genesis of Certain Auriferous Lodes, by J. R. DON: Trans. Am. Inst. Min. Eng., Vol. XXVII, 1898, p. 596.

[5] The Gold-quartz Veins of Nevada City and Grass Valley, California, by WALDEMAR LINDGREN: Seventeenth Ann. Rep. U. S. Geol. Surv., 1895–6, Pt. II, p. 128, 1896.

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is believed to be the result of a single concentration by ascending waters. Such ore deposits may continue without any appreciable diminution in richness to the lowest limits to which man may expect to penetrate the earth; but these are exceptional cases. Even ore deposits which are the result of a single concentration by ascending water may diminish in richness at considerable depth. It has been seen that in the fissure at the bottom of the valley on this chart (Fig. 6) that the water ascends to the surface. It is evident that the upper part of the fissure receives the greatest supply of water, and this water to a large extent does not penetrate any great depth; while the lower part of the fissure receives less water, but this water penetrates to a considerable depth. It may happen that the water relatively near the surface traverses the rocks containing the main supply of metals and therefore brings the chief contributions of valuable material, or such waters may carry the precipitating agent. In such instances the ore deposits produced by ascending water alone, would diminish in richness with depth; but such decrease would not be likely to be very rapid. Upon the other hand, if the above conditions be reversed, a deposit may increase in richness for a considerable depth; but as a matter of fact this appears to be a very infrequent case.

As illustrations of the ore deposits of the class produced by ascending waters alone are the copper deposits of Lake Superior. These deposits, while very bunchy and extremely irregular in the distribution of copper, are wonderfully persistent in depth. The copper of the ore was deposited in the metallic form. As compared with sulphides, this material is not readily oxidized. In this district the rocks above the level of groundwater are not appreciably weathered. Doubtless there was a belt of weathered material before the glacial epochs, but if so, it has been swept away by ice erosion; and since the glacial period sufficient time has not elapsed to weather appreciably the rocks which now lie within the theoretical belt of weathering. If there once were in this district an upper belt of weathering in which there were deposits of exceptional richness, this

material has been removed. However, in this district, a first concentration by ascending waters was adequate, but it is not often that a first concentration produces deposits of such richness as those adjacent to Calumet and Houghton on Keweenaw Point; and, indeed, this is exceptional even in the Keewenawan of the Lake Superior region; for while concentrations of copper have occurred at many points in the rocks of this period, as yet at no other locality have those concentrations been found to be so abundant and rich as to warrant exploitation on a large scale.

I now turn to the question as to the cause of frequent diminution of richness of ore deposits with depth. Many or most of such ore deposits are believed to be the products of two concentrations, the first by ascending, the second by descending waters. In this connection it is necessary to call attention to the fact that a large proportion of the ore deposits which are being exploited are below some part of a slope. It may be said that the reason for this is that the low grounds are more difficult to explore and work, but giving due allowance for this, it still seems to me that the majority, perhaps the great majority, of very rich deposits are below slopes and crests, and not below the valleys. I believe the richer deposits are below the slopes, because at these places a second concentration is possible and probable.

Returning now to this chart (Fig. 6) we shall direct our attention to the fissure on the slope. This fissure once extended up through the overlying rocks which have been removed by denudation. What has become of the ore in the part of the fissure which has been worn away? If, for instance, it carried 5 per cent. of copper, what has become of it? A part of it would have been scattered far and wide through erosive action; but a part of it would have been taken into solution and redeposited in the same vein deeper down. In the belt of weathering oxidized salts, such as sulphates, would form; the descending waters would carry these products downward; and it is my belief that they would react upon the solid, lean sulphides below with the result of precipitating the metals from the descending solutions.

Now this has been held to be a mere unverified assumption by some geologists, but it seems to me that they have not fully considered the certain effects of the chemical laws concerned. We know if in a laboratory a solution of copper sulphate or other copper salt be placed in contact with iron sulphide, that copper will be thrown down as copper sulphide. If the copper solution be placed in contact with a lean copper-iron sulphide, a sulphide richer in copper will be produced. And if these reactions occur in the chemical laboratory, will they not as certainly occur in the laboratory of nature, although perhaps more slowly?

At this point it is to be recalled that in many copper deposits above the level of groundwater oxides and carbonates occur, while below the level of groundwater are sulphides. Moreover, at high levels these sulphides are rich in copper, and they usually become poorer in copper sulphide and richer in iron sulphide at the lower levels. You will remember at Butte, Mont., at and for a distance below the level of the groundwater, are rich copper sulphurets which grade at depth into leaner copper sulphides containing correspondingly large amounts of iron sulphide. You will remember the same is true for the entire Appalachian region. You will remember that frequently above the level of groundwater gold lodes are exceedingly rich. What is the explanation of these and similar facts? What is the explanation of the exceptional or even extraordinary richness of the deposits at and near the level of groundwater, and of the low grade of cupriferous pyrites deep below the level of groundwater. In my opinion the only plausible explanation is that the rich parts of the deposits have received two concentrations, the first by ascending waters and the second by descending waters. The metals of the rich portions of the deposits were largely contributed by the parts of the deposit above, or once above, the rich parts. In some cases portions of the depleted veins remain, as at Butte; but frequently the depleted parts of the veins have been removed by erosion. The remote source of the material was, therefore, the metals deposited by the first concentration.

But let us follow the matter still farther. In the majority of cases, as denudation continued, the parts of the ore deposits produced by the second concentration rise into the belt of weathering. They may there be partly or wholly transformed into rich oxidized products, or they may be depleted to extend the rich deposits below. In the concentration by descending waters the chief chemical reactions are believed to be between the oxides or salts of copper and the sulphide of iron. The precipitation of copper sulphide resulting may occur in various ways.

The reaction may produce chalcopyrite, as shown by the following equations:

$CuSO_4+2FeS=CuFeS_2+FeSO_4$, or

$CuSO_4+2FeS_2+O_4=CuFeS_2+FeSO_4+2SO_2$.

The reactions may produce bornite, as shown by the following equations:

$Cu_2SO_4+CuSO_4+3FeS=Cu_3FeS_3+2FeSO_4$, or

$Cu_2SO_4+CuSO_4+3FeS_2+6O=Cu_3FeS_3+2FeSO_4+3SO_2$.

Or the reactions may directly produce chalcocite, as shown by the following equations:

$Cu_2SO_4+FeS=Cu_2S+FeSO_4$, or

$Cu_2SO_4+FeS_2+O_2=Cu_2S+FeSO_4+SO_2$.

If the reactions are between a copper salt and sulphide bearing copper various reactions throwing down the copper may also occur. The reactions may be upon chalcopyrite producing bornite, as shown by the following equation:

$2CuFeS_2+CuSO_4+O_2=Cu_3FeS_3+FeSO_4+SO_2$.

It may be the reaction of copper sulphate upon chalcopyrite or bornite producing chalcocite, as shown by the following:

$CuFeS_2+CuSO_4+O_2=Cu_2S+FeSO_4+SO_2$, or

$Cu_3FeS_3+CuSO_4+O_2=2Cu_2S+FeSO_4+SO_2$.

It may be by the reaction of copper oxide or copper sulphate upon covellite producing chalcocite, as shown by the following equations:

$6CuS+2Cu_2O=5Cu_2S+SO_2$, and

$6CuS+2Cu_2SO_4+3H_2O=5Cu_2S+2H_2SO_4+H_2SO_3$.

Parallel sets of reactions could be, and indeed are written in my full paper upon the subject of ore deposits, which explain the formation of the rich sulphides of lead, zinc, and silver through the reactions of the oxidized products of these metals upon sulphide of iron, producing rich sulphides of lead, zinc, and silver. However time does not suffice to present these this evening. The particular reaction in an individual case will depend upon the relative solubilities of the various compounds present, upon the law of mass action, upon the pressure and temperature, and upon various other factors.

Now I do not assert of the equations which have been written for copper and the other metals that the reactions represented occur exactly as written, but I do assert that reactions of the general character represented occur by which the oxidized products of the metals in solution are thrown down by the lean sulphurets, producing rich sulphurets. I have no doubt that many other reactions besides those written take place. It is exceedingly difficult to ascertain the particular reactions which occur at a given time and place; but I think it is perfectly clear that reactions occur of the type of those written. I cannot attempt to give you all the evidence on the point, but to me the case is demonstrative. If this be correct we now have an explanation of the fact that a great many ore deposits are rich at high levels and become poorer with depth. These ore deposits have undergone two concentrations, a first concentration deposited by ascending waters and a second concentration deposited by descending waters. The supplies for the first concentration were obtained from the widely dispersed and small amounts of material disseminated through the rocks. The supplies for the second concentration were derived from an earlier concentration.

In the foregoing statements the second concentration of metals by solution, downward transportation, and precipitation by reactions upon the sulphides of an earlier concentration has been emphasized. However, it is not supposed that this is the only process which may result in enrichment of the upper parts of ore-deposits by descending waters. The enrichment of this

belt may be partly caused (1) by reactions between the downward moving waters carrying metallic compounds and the rocks with which they come in contact, and (2) by reactions due to the meeting and mingling of the waters from above and the waters from below.

(1) The metallic compounds dissolved in the upper part of the veins, carried by descending waters, may be precipitated by material contained in the rocks below. This material may be organic matter, ferrous substances, etc. So far as precipitating materials are reducing agents, they are likely to change the sulphates to sulphides, and precipitate the metals in that form. While sulphides may thus be precipitated either above or below the level of groundwater, they are more likely to be thrown down below the level of groundwater. Other compounds than reducing agents or sulphides may precipitate the downward moving salts in other forms than sulphides.

(2) In a trunk-channel, where waters ascending from below meet waters descending from above, there will probably be a considerable belt in which the circulation is slow and irregular, the main current now moving slowly upward and now moving slowly downward, and at all times being disturbed by conventional movements. Doubtless this belt of slow general movement and conventional circulation would reach a lower level at times and places of abundant rainfall than at other times and places, for under such circumstances the descending currents would be strong. The ascending currents, being controlled by the meteoric waters falling over wider areas, and subject to longer journeys than the descending currents, would not so quickly feel the effect of abundant rainfall. Later, the ascending currents might feel the effect of the abundant rainfall and carry the belt of upward movement to a higher level than normal. However, where the circulation is a very deep one, little variations in ascending currents result from irregularities of rainfall.

In the belt of meeting ascending and descending waters (see Fig. 6) conventional mixing of the solutions due to difference in temperature would be an important phenomenon. The waters

rom above are cool and dense, while those from below are warm and less dense. In the neutral zone of circulation the waters from above would thus tend to sink downward, while waters from below would tend to rise, and thus the waters would be mingled. Still further, even if the water were supposed to be stagnant at the neutral belt, it is probable that by diffusion the materials contributed by the descending waters would be mingled with the materials contribùted by the ascending waters.

Ascending and descending solutions are sure to have widely different compositions, and precipitation of metalliferous ores is a certain result. As a specific case in which precipitation is likely to occur, we may recall that waters ascending from below contain practically no free oxygen and are often somewhat alkaline, while waters descending from above are usually rich in oxygen and frequently contain acids, as at Sulphur Bank, described by Le Conte.[1] The mingling of such waters as these is almost sure to result in precipitation of some kind. Le Conte further suggests[2] by the mingling of the waters from below with those from above that the temperature of the ascending column will be rapidly lessened, and this also may result in precipitation, but the dilution would work in the reverse direction.

The metals precipitated by the mingling of the waters may be contributed by the descending waters, by the ascending waters, or partly by each. In so far as more than an average amount of metallic material is precipitated from the ascending waters, this would result in the relatively greater richness of the upper part of veins independently of the material carried down from above.

In all the cases considered the precipitation and enrichment of the upper parts of deposits follow from the reactions of downward moving waters. Their effect may be to precipitate the metals of the ascending water to some extent and thus assist in the first concentration. But the results of these processes

[1] On the Genesis of Metalliferous Veins, by JOSEPH LE CONTE: Am. Jour. Sci., 3d ser., Vol XXVI, 1883, p. 9.

[2] LE CONTE, op. cit., p. 12.

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process, that both may work together at an ir
and that descending waters are likely to be th
the closing stage of the process.

Also, for the sake of simplicity in the co
concentrations I have disregarded the lateral
moving water. In many cases superimposec
cal movements in the fissures or other ope
movements, as a result of which the deposits ii
vertical positions are inclined, often much inc
may be horizontal or even locally descendin

horizontal extents of the deposits may be much greater than the vertical extents. Reduced to a simple and broad statement, *The first concentration of many ore deposits is the work of a relatively deep water circulation, while the reconcentration is the result of reactions upon an earlier concentration through the agency of a relatively shallow water circulation. Commonly the deep water circulation is lacking in free oxygen and contains reducing agents, and the shallow water contains free oxygen. The deep water is therefore a reducing, and the shallow water an oxidizing agent.*

In addition to the general factors already considered there are many special factors which have a most important, indeed, very often a controlling influence in the production of ore-chutes and in the localization of ore in certain areas and districts. Some of these factors are the complexity of openings, the presence of impervious strata at various depths, the presence of pitching folds, the character of the topography. I see however that my time is nearly gone, and I shall not take up their discussion this evening, but must refer those especially interested in this phase of the subject to my full paper already repeatedly mentioned.[1] I must however note that impervious strata are frequently of controlling importance in the underground circulation. Often deep and shallow water circulations are separated by such strata. Often also as the result of the removal of impervious strata by denudation, the previous deep circulation ceases and the action of the shallow circulation is inaugurated.

At this point it may be well to briefly recall the most fundamental features of the water circulation which produces the ore deposits. First comes the downward-moving, lateral-moving waters of meteoric origin which take into solution metalliferous material. These waters at depth are converged into trunk channels, and there, while ascending, the first concentration of ore deposits may result. After this first concentration many of the ore deposits which are worked by man have undergone a later concentration not less important than the earlier, as a result of

[1] Some Principles Controlling the Deposition of Ores, by C. R. VAN HISE: Trans. Am. Inst. Min. Eng., Vol. XXX, 1900, pp. 112–146.

shallow descending or lateral-moving waters. In other cases a concentration by descending, lateral-moving waters alone is sufficient to explain some ore deposits. It thus appears more clearly than heretofore that an adequate view of ore deposits must not be a descending-water theory, a lateral-secreting water theory, or an ascending-water theory alone. While an individual ore deposit may be produced by one of these processes, *For many ore deposits a satisfactory theory must be a descending, lateral-secreting, ascending, ascending lateral-secreting theory.*

But there is no question in my mind that this theory is still insufficient to fully explain many of the ore deposits. No knowledge is ever complete. We move step by step, carrying a theory nearer and nearer completion. If, however, a theory be based on good work it usually will not prove to be false; it will be found to be incomplete. Sandberger was not wrong when he said lateral secretion explained many things in reference to ore deposits. He was wrong only when he excluded other factors. He became unscientific when he carried his theory further than his observations justified. While the theory here proposed is believed to mark an important advance, it will sooner or later be found to be incomplete. I trust it will not be found to be false. The most that I can hope for it is that it is approximately correct as far as it goes.

It seems to me that the principles which have been presented give a basis for a natural classification of the ore deposits produced by underground water. As already noted, ore deposits may be divided into three groups: (1) ores of igneous origin, (2) ores which are the direct result of the processes of sedimentation, and (3) ores which are deposited by underground water.

Since the ores produced by igneous agencies and those produced by processes of sedimentation have not been considered in this paper, a subdivision of these groups will not be attempted.

Ores resulting from the work of groundwater, group (3) above, may be divided into three main classes:

(*a*) Ores which at the point of precipitation are deposited by ascending waters alone. These ores are usually metallic or

some form of sulphuret; but they may be tellurides, silicates, or carbonates.

(*b*) Ores which at the place of precipitation are deposited by descending waters alone. These ores are ordinarily oxides, carbonates, chlorides, etc., but silicates and metals are exceptionally included.

(*c*) Ores which receive a first concentration by ascending waters and a reconcentration by descending waters. The concentration by ascending waters may wholly precede the concentration by descending waters, but often the two processes are at least partly contemporaneous. The materials of class (*c*) comprise oxides, carbonates, chlorides, and rarely metals and silicates above the level of groundwater, and rich and poor sulphurets, tellurides, metallic ores, etc., below the level of groundwater. At or near the level of groundwater, these two kinds of products are more or less intermingled, and there is frequently a transition belt of considerable breadth.

How extensive are the deposits of class (*a*) I shall not attempt to state. Indeed, I have not such familiarity with ore deposits as to entitle me to an opinion upon this point. However a considerable number of important ore deposits belong to this class. This class is illustrated by the Lake Superior copper deposits.

The ore deposits of class (*b*) are important. Of the various ores here belonging probably the iron ores are of the most consequence. A conspicuous example of deposits of this kind are the iron ores of the Lake Superior region.

It is believed that the ore deposits of class (*c*) are by far the most numerous. I suspect that a close study of ore deposits in reference to their origin will result in the conclusion that the great majority of ores formed by underground water are not the deposits of ascending waters alone, but have by this process undergone an early concentration, and that descending waters have produced a later concentration, as a result of which there is placed in the upper 50 to 500 or possibly even 1000 meters of an ore deposit a large portion of the metalliferous material

which originally had, as result of the early concentration, a much wider vertical distribution.

To the foregoing classification objections will at once be made: It will be said that there are no sharp dividing lines between the groups and classes. To this objection there is instant agreement. Transitions are everywhere the law of nature. It is well known that there are gradations between different classes of rocks,[1] and this statement applies equally well to ore deposits. I even hold that there is gradation between ore deposits which may be explained wholly by igneous agencies and those which may be explained wholly by the work of underground water or by processes of sedimentation.

I have elsewhere held that there is complete gradation between waters containing rock in solution and rock containing water in solution.[2] If there be no sharp separation between water solutions and magma it is probable that this is also true in reference to ore deposits of direct igneous origin and those produced by underground water. There may be ore deposits in which water action and magmatic differentiation have been so closely associated that one cannot say whether the resultant ore deposit is mainly a water deposit or mainly a magmatic deposit. But for the vast majority of ore deposits, if I properly apprehend the relations, the broad general statements which I have made apply. Ordinarily there is little difficulty in discriminating between veins and dikes, the first representing crystallizations from water solutions, the second crystallizations from magma. There are few cases where the discrimination in reference to ore deposits is not easy. While gradations between water deposited ores and igneous ores are uncommon, gradations between the different classes of ore deposits formed by underground water are common.

Ores which have received a first concentration by igneous agencies or by processes of sedimation are sure to be reacted upon by the circulating underground waters, and thus a second

[1] The Naming of Rocks, by C. R. VAN HISE: Journ. of Geol., Vol. VII, 1899, pp. 687, 688.

[2] Principles of North American pre-Cambrian Geology, by C. R. VAN HISE: Sixteenth Ann. Rept. U. S. Geol. Surv., 1894–5, Pt. I, p. 687.

or even a third concentration may take place. The first concentration by igneous or sedimentary processes may be the more important or dominant process, or the additional concentration or concentrations by underground waters may be the more important or dominant process. In some cases therefore the ores may be referred to as produced by igneous agencies, in others as produced by processes of sedimentation, in others as produced by these in conjunction with underground waters, and in still others as produced mainly by underground waters.

Ore deposits which are precipitated almost solely by ascending waters will grade into those in which descending waters have produced an important effect, and thus there will be transition between classes (*a*) and (*c*). Similarly there will be every gradation between classes (*a*) and (*b*) and between classes (*b*) and (*c*). If this be so it will not infrequently happen that a single fissure may fall partly in one class and partly in another. Thus a single ore deposit may belong partly in class (*a*) and partly in class (*c*). However, in most cases the workable part of a deposit will largely belong to one of the three classes.

Not only are there gradations between different varieties of the ore deposits, but there are gradations between the ore deposits and the rocks; for the ore deposits in many cases are not sharply separated from the country rocks, but grade into them in various ways.

In answer to the above objection concerning gradations, it may be said that I know of no classification of ore deposits which has yet been proposed to which the same objection may not be urged with equal or greater force.

However this retort does not give any criterion by which the usefulness of the above classification may be tested. The test is, does this classification give a more satisfactory method of studying ore deposits than has heretofore been possible? Will an attempt to apply this classification assist mining engineers and geologists in accurately describing ore deposits? Will the classification to a greater extent than any previous one give engineers rules to guide them in their expenditure in exploration

and exploitation? By these criteria I am willing that the classification shall be tested.

As an illustration of the practical usefulness of the classification is the connection between genesis and depth. The character of a deposit in most cases will determine to which class it belongs. Where the ores are deposited by ascending waters alone it has been pointed out that this is favorable to their continuity to great depth. Therefore, where a given ore deposit has been shown to belong to this class, the expenditure of money for deep exploration may be warranted, although, as already pointed out, p. 757, such deposits may decrease in richness with depth. Where a deposit is produced by descending waters alone, the probable extent in depth is much more limited. In such cases, when the bottom of the rich product is reached, it would be the height of folly to expend money in deep exploration. Where the ore deposit belongs to the third class, that produced by ascending and descending waters combined, there will, again, be a richer upper belt composed of rich oxidized and sulphureted deposits which we cannot hope will be duplicated at depth. To illustrate: it would be very foolish, at Ducktown, Tenn., to sink a drill hole or shaft into the lean cupriferous pyrrhotite with the hope of finding rich sulphurets such as those which were mined near the level of groundwater. Those who have spent money in deep prospecting of the lean pyrrhotite in the Appalachian range will doubtless agree to this statement. Deposits produced by two concentrations may grade into the class produced by ascending water alone, and after the transition the deposit may be rich enough to warrant exploitation at depth; but if such work be undertaken it must be done with the understanding that the rich upper products will not be reduplicated at depth. It therefore appears to me that the determination to which of the classes of ore deposits produced by underground waters a given ore deposit belongs has a direct and very important practical bearing upon its exploration and exploitation.

C. R. VAN HISE.

REVIEWS

Secondary Enrichment of Ore Deposits. By S. F. EMMONS. Trans. American Inst. Min. Eng., Vol. XXX, 40 pp., 1900.

Enrichment of Gold and Silver Veins. By WALTER HARVEY WEED. Trans. Amer. Inst. Min. Eng., Vol. XXX, 25 pp., 1900.

In the exploitation of ore bodies it has been found that many deposits decrease in richness as depth increases. The explanations have been various. That the phenomenon is a far more general one than was once supposed, has only recently been recognized in its full significance. It may be expected to be very frequently met with, now that its real character has been found out, by all students of ore deposition.

It is now a well-known fact that as geological formations, ore-bodies as a rule are to be regarded as deposits originating very near the surface of the earth's crust; or, to be more precise, in the thin outer belt of the zone of fracture of the lithosphere. The unusual richness of many ore deposits at very shallow depths has come to be considered as due to local enrichment, often long after the first concentration has taken place.

From the viewpoint of origin, diminution of richness with depth is not, then, to be ascribed to actual depreciation in the original grade of the ore. The real status of the case is that the deposition of ore has, in the upper belt, undergone a greater or less augmentation in metallic content since the body was first formed.

Among those who have given the subject of ore genesis most attention, and especially among those who have approached the subject from the geological side, the rival theories of ascending solutions, descending solutions, and laterally moving solutions, no longer find countenance as distinct processes. Ore deposition may take place through all three means, which may have equal importance. After an ore deposit has once formed under special geological conditions, the secondary enrichment which it may undergo is believed to take place largely under the influence of the descending solutions.

In the exploitation of the ore-bodies, it all goes to show how vitally important is a full consideration of the geological structures presented at the time of the first concentration, and as subsequently assumed.

The keynote of Mr. Emmons' paper is given in one of the opening paragraphs, when he says that "admitting fully the general truth of the statement that the descending surface waters exert an oxidizing action, and hence that oxidation products within the reach of surface waters are the result of the alteration by the latter, I have been led to believe, by observations now extending over a considerable number of years, that under favorable conditions the oxidation products may be changed back again into sulphides and redeposited as such, thus producing what may be called a sulphide enrichment of the original deposits. . . . . Being rather a searcher after facts than a theorist, I am not deterred from accepting what may appear to me the correct reading of observed facts, because it seems to contradict generally accepted theories."

After briefly discussing the circulating waters of surface origin, the groundwater level, the deposition of oxides below water-level, and the deposition of sulphides, the author goes on to give an account of many cases of secondary enrichment which his wide experience has brought to notice. This account occupies the greater part of the paper. The three propositions following are believed to be substantiated by the geological evidence adduced:

1. That descending waters not only cause migrations, or transference and reconcentration, of the alteration products of the original vein-materials in oxidized form, producing in one place an enrichment, and in another possibly an impoverishment of the original deposit, but that in their further downward course the oxidized forms are frequently reduced and redeposited as sulphides, thereby producing a sulphide enrichment of the original vein-materials.

2. That this secondary enrichment of sulphides is not necessarily a reduction in the presence of organic matter, but is frequent where no organic matter can be supposed to be present. It occurs mainly in contact with the original sulphides of the deposits, and is, presumably, a result of chemical reaction between these sulphides and the materials brought down in solution by the descending waters.

3. That while this redisposition of sulphides in many cases appears to commence at or near the groundwater-level, it does not appear to

have a necessary connection with that level, and may under favorable conditions extend below that level for a distance as yet undetermined, the most important favoring conditions appearing to be recent or post-mineral fractures, which have admitted a relatively free and uninterrupted descent of these waters.

In conclusion, students are cautioned against making the inference too sweeping. "Until a much larger number of ore deposits have been studied with a definite purpose of determining how far they have been subjected to secondary enrichment, it does not seem safe to draw any far-reaching conclusions from the observations and suggestions noted above. It has long been recognized that the superficial alteration of ore deposits has often produced a very considerable modification of the original constitution of the deposit, and its alteration has so frequently been in the nature of an enrichment in the more valuable metals relatively to the original tenor of the ores, that it has given rise to the very hasty decision that all ore-deposits necessarily become poorer in depth, which is almost as unjustifiable as the old assumption by the miner, that the nearer he got to the source of his ore in the unknown deposits, the richer it would become.

"The fact that ores under some conditions may be removed and redeposited as sulphides, even below groundwater-level, opens a wide field of possibility in accounting for the unusually rich bodies of ore that are in some mines found in the middle levels, and have been fruitlessly sought for at greater depth. In many cases these have undoubtedly resulted from a concentration of material leached down from the upper portions of the deposit as they have been worn down and carried away by denudation. Especially in the case of large bodies of pyritous ore carrying small proportions of more valuable metals, is a concentration of those metals by downward percolating solution to be looked for. It is, however, not yet safe to say that all rich bonanzas in vein deposits have necessarily been formed in this way."

The paper by Mr. Weed gives a brief statement of the theory enunciated in a former contribution. The principles are applied more particularly to the deposits of the precious metals, with special emphasis laid upon the dependence of such enrichments upon the presence of iron sulphide in the primary ore, and upon the structural features which control the circulation of the enriching solutions below groundwater-level. The discussion is largely of Montana deposits, which the author has been engaged in studying for several years past. Regarding

the theoretical chemical changes, those taking place in each of the several zones are considered in detail.

Leaching out of the metals from the portion of the vein lying above groundwater-level is considered as the main source of the enriching materials. The alteration at the surface leaves the iron as a gossan, while the waters carrying the gold, silver, copper, and other metals in solution trickle downward through the partially altered ores into cracks and water-courses which penetrate the ore-body below the water-level. The first of the process is, therefore, the leaching of the lean ores which occurs in the superficial alteration of the vein. In weathering, the sulphides oxidize according to their relative affinity for oxygen and inversely as their affinity for sulphur. It is concluded from the evidence that ore-bodies lacking in iron pyrite will not show enrichment, thus explaining the absence of any such phenomena in the pure silver-lead bodies of the Coeur d'Alene district and elsewhere.

The observations of the author on the effects of physiographic and climatic changes, and on the changes of water-level, are of exceptional significance: "Active degradation favors the accumulation of enrichment, while prolonged degradation of a region, resulting from physiographic revolutions, may result in successive migrations of material and the accumulation in a relatively shallow zone of the metals derived from many hundreds, and possibly thousands, of feet of the vein worn away in the degradation of the land. Climatic conditions, rainfall or aridity, warmth and rapid alteration of vein fractures, are agents affecting surface weathering, and hence, also, enrichment.

"Active degradation of a region, that is, rapid weathering, favors enrichment by the quickness with which it removes the upper already leached part of the vein, so that a larger amount of the vein-matter is lixiviated in a given time than would result from the slower wasting of the land. Such enrichments are favored by high latitudes. Moreover, the mountainous regions are those in which secondary fractures are most apt to be found.

"Prolonged degradation is favorable for a similar reason, since time is a factor in enrichment and changes in elevation, etc., affect the rate and the progress of decay of the vein; while the crustal movements accompanying the physiographic changes favor fracturing of the earlier deposit, increasing facility of leaching and place for deposition. If a region passes through several cycles of erosion and elevation, it is evident that their result is likely to be a succession of enrichments in

which not only the original ore is leached, but the earlier enrichment deposits migrate downward. At Butte, Mont., the region has passed through several very pronounced changes in elevation since the formation of veins in Tertiary time. In early Tertiary time the present topography of the region was blocked out, and mountain ranges and deep valleys carved. This was succeeded by earth movements by which the streams became clogged or the valleys dammed, forming lakes; while volcanoes broke out at numerous places and showered ashes and scoria over the region. The valleys were silted up or in part filled with volcanic débris before crustal movements drained the valleys and altered the divides. More recent movement, possibly still continuing, is marked by faults and a reversing of the stream courses. The old valley at Butte is filled by hundreds of feet of débris, and a mountain wall 2500 feet high marks a north and south fault-line. These changes all caused a migration of water-level facilitating the processes of weathering and enrichment, and the great bodies of rich copper ores of the region are believed to be in part due to this cause."

CHARLES R. KEYES.

Enrichment of Mineral Veins by Later Metallic Sulphides. By WALTER HARVEY WEED. Bull. Geol. Soc. Am. Vol. XI, pp. 179–206, 1900.

The author calls attention to the occurrence of localized masses of exceptionally rich ore in mines of copper, silver and zinc, which he undertakes to explain as the result of enrichment by processes subsequent to the deposition of the lower grade ore. The paper attempts to show that these richer bodies of sulphide ore are formed by the redeposition of material leached from the vein, generally by superficial waters, and to show the chemical and mineralogical changes involved, as well as the physical conditions under which redeposition took place. The ores in question are chiefly the high grade sulphides.

He describes three zones; that of oxidation, that of sulphide enrichment, and that of primary sulphides, and refers to the writings of DeLaunay, Prosepny, Penrose, Emmons and Kemp in this connection. In discussing the chemical and mineralogical changes supposed to take place, he compares unaltered and altered ore and drainage waters observed by himself and cites freely from the literature of the subject, concluding that together they show that the original ore is

leached by surface waters, which take into solution various metals and passing downward meet with and are decomposed by the sulphides of iron present in the unaltered ore, resulting in the redeposition of new sulphides of the metals.

This is followed by a description of the mode of occurrence of secondary sulphide ores of copper, silver, and zinc, as studied by the author and others. The enrichment in many cases proceeds along barren fractures producing bonanzas. In others it forms films, paystreaks, or ore shoots in the body of leaner original ore. In still other cases the alterations are produced by deep-seated uprising waters acting upon the vein. As a consequence of these processes veins do not increase in richness in depths below the zone of enrichment.

J. P. I.

Origin and Classification of Ore Deposits. By CHARLES R. KEYES. Trans. American Inst. Mining Eng., Vol. XXX; 34 pp., 1900.

The various attempts that have been made in the past to formulate a rational and at the same time a useful classification of ore deposits have met with only indifferent success. The fundamental factor in the proposed scheme by Dr. Keyes is geological in nature. It is based upon the principle that local deposition and specific form of the ore body is dependent upon geological structures, and these largely govern also the exploitation of the ores. This is believed to be as nearly as it is possible to approach a purely genetic arrangement. The great geological processes are made the governing principles.

Although the present memoir discusses only the classificatory aspects of the ore deposits, it is an application of the modern principles of petrology, and especially those dealing with the processes involved in general rock metamorphism, and it opens the field for fuller explanations and applications of these principles.

Three propositions are emphasized: First, ore bodies with few exceptions are regarded as essentially surface deposits—that is, they are considered as confined to a very thin zone near the earth's surface, or more precisely in the outer belt of the zone of fracture of the lithosphere; second, most of the worked deposits of the globe are thought to be of very late geological formation, probably few dating back before the Tertiary; third, ore bodies are believed to be concentrated chiefly

by circulating waters that have come up from below, down from above, or in from the sides, it being immaterial from which direction.

Of recent years there has been a growing tendency for the large mining companies to pay more attention to the geological features of their properties, and in many cases a regularly trained geologist has been employed. Dr. Keyes emphasizes this fact when he says that "When a specially trained geologist undertakes to make an investigation of a mining property, he first gets his bearings, as it were, with regard to the geological structure of the region and the distribution of the rock formations. At once he eliminates nine tenths of the chances of failure in arriving at the best plan for practical operation. Instead of a great game of chance, the development becomes a strictly business proposition."

After briefly discussing the nature of ore deposits, the general methods of ore formation, and the character of the literature, the criteria for ore classification are formulated. The following table sums up the proposed scheme:

CLASSIFICATION OF ORE DEPOSITS.

Groups.	Categories.	Miners' Forms.
I. HYPOTAXIC. Mainly surface deposits.	Aqueous transportation.	Placers.
	Residual cumulation.	Pockets (in part).
	Precipitative action.	Bog-bodies, some beds, layers.
II. EUTAXIC. Chiefly stratified formations.	Original sedimentation.	Beds, strata, layers.
	Selective dissemination.	Impregnations (in part).
	Emponded amassment.	Masses (in part), some segregations.
	Fold-filling.	Saddle-reefs.
	Crevice accretion.	Gash-veins, stock-works (in part).
	Concretionary accumulation.	Nodules.
	Metamorphic replacement.	Fahlbands (in part), beds.
III. ATAXIC. Predominantly unstratified and irregular bodies.	Magmatic secretion.	Masses (in part), some lenses.
	Metamorphic segregation.	Stocks, lenses.
	Fumerole impregnation.	Contact-veins, some impregnations.
	Preferential collection.	Chambers (in part), some pockets, linked-veins.
	Fissure occupation.	Attrition-veins (in part), some linked-veins, true veins.

The principal points which the memoir dwells upon are:

1. The main feature wherein the scheme of classification offered differs from others is in the prominence given to geological occurrence and the direct operation of the geological processes as essential factors in the genesis of ore bodies.

2. The nearest approach to a purely genetic classification of ore deposits is believed to be found in their geological relationships, as determined by the great groups of geological processes, and not in their direct chemical formation or physical shapes.

3. The chemical reactions so widely used as criteria of ore classification are to be regarded as general agencies, and therefore they are not available in the specific determinations of the various classes of ore bodies.

4. In the discovery and exploitation of ores, structure is of first importance, that is, the structure of the inclosing country rocks.

5. The primary groupings of ore bodies appear to be best indicated when based upon their geological occurrence, as governed by the nature of geological processes operating.

6. The secondary groupings appear to be best based upon the general form of the ore bodies as geological formations produced by the grander geological agencies.

7. The ternary groupings are best based upon the specific phases of the geological processes involved in the formation of ores as ore bodies.

8. The source of the ore materials is an unessential factor in their classification, the great practical question being, how are ores best exploited? In this connection it matters little what was the original condition of the ores. Nor have we to do very much with the detailed, complex, and usually fanciful chemical reactions that are supposed to take place before the final stage of the ore, as we find it, is reached.

9. Ore bodies of very similar appearance may be formed by very different methods—a fact which, while apparent in all classifications, does not necessarily vitiate any.

10. Finally, the proposed scheme is merely suggestive. It is the barest outline of what is believed to be capable of much farther expansion and development into a comprehensive, rational, and practical general plan.

C. F. M.

Éléments de Paléobotanique. By R. ZEILLER. 8vo, pp. 421, with 210 illustrations. Paris: Georges Carré et C. Naud, 1900.

The great needs of recent years in Paleobotany have been a summary of the scattered materials and the delimitation of well-founded data from data that are more or less uncertain. A great stride forward has been taken along these lines and as a result we are in a position to speak more categorically as to plant fossils. The first part of Professor Seward's work appeared sometime ago and has been reviewed in these pages[1]. Almost simultaneously three valuable works have recently appeared, one in English by Professor Scott, one in German by Potonié, and the one which is the subject of this review. The standpoint of the three works is somewhat different, Scott taking the standpoint more of the morphologist, Potonié of the stratigrapher, while Zeiller combines the botanical and geological standpoints, though giving more emphasis to the botanical side. More than any book that has yet appeared, this is a book to be used with impunity by general readers and elementary students. The first chapter treats of the various methods by which plant fossils have been preserved, then follows a chapter on classification and nomenclature. The body of the book, of course, is made up of descriptions of the various fossil forms treated in order. The cuts are simple but clear and good, and the descriptions are doubtless the shortest and clearest that are found anywhere.

The conservatism of the author is shown at many points, and the difference between established and hypothetical data is clearly brought out. As an illustration of this, Zeiller constantly distinguishes between forms based on leaves and forms based on reproductive organs, as in the ferns. There are interesting discussions of the Sphenophylleæ and the Cycadofilices, though the author does not go so far as some in putting these forms in great groups by themselves.

At the close of the book are two chapters of extreme interest. The chapter on the succession of floras and climates is wonderfully meaty, and it is doubtful if a better summary of the known facts was ever written, certainly not in a shorter compass. The author theorizes but little from the facts presented, and such deductions as he makes in regard to climate are extremely conservative. The last chapter must be somewhat startling to many readers, as Zeiller thinks there is very little evidence from fossil plants in favor of gradual evolution. He states that in almost every case, species, genera, families, and

[1] JOUR. GEOL.: Vol. VI, p. 436, 1898.

groups appear highly specialized and in their permanent form from the first. So-called intermediate forms like Cheirostrobus appear long after the forms they are supposed to connect. Genera and species that vary now have always varied and the limits of variation now and in the past have been the same and definitely prescribed. In short Zeillar believes that the evolution of all groups is a matter almost purely of speculation. Doubtless most scientists will fail to accept Zeiller's views as to evolution, and yet it may be well to put a brake now and then to unlimited speculation; a perusal of Zeiller's final chapter certainly compels one to do that.—H. C. COWLES.

A Topographic Study of the Islands of Southern California. By W. S. TANGIER SMITH. Bulletin of the Department of Geology. University of California, Vol. II, pp. 179–230. 1900.

This bulletin involves an account of certain islands which have been studied in the field, and of others which have been studied from maps only. Following a description of the general topography of the islands, there is a somewhat full discussion of certain coastal features, especially of wave-cut terraces, and of wave and current-built features. This discussion is incisive, and will be of service to the student of coastal topography.

Following the descriptive matter there is a sketch of the history of the islands, from which the following extracts are made:

> It is generally assumed that the broad physical features of the Pacific Coast were largely developed during the prolonged period of erosion between the Miocene and Pliocene,[1] and that these forms have been modified more or less by subsequent movements, both general and local, as well as by subsequent erosion and deposition. During the Miocene the land was depressed, as indicated by the Miocene deposits, the nonconformity between these and the Pliocene deposits showing a period of subaerial erosion, during which the land was more elevated than at present. This period of elevation and erosion was followed by the Pliocene depression, during which deposits of great thickness were laid down in favorable localities, the larger Miocene valleys being filled to a greater or less extent with deposits which have since been re-excavated to a greater or less extent.

[1] By the long interval between the Miocene and Pliocene is doubtless meant the long interval between the deposition of the California coastal Miocene, and the Pliocene of the same region.

During the post-Miocene interval, it is probable that all the islands then differentiated were mountainous masses belonging to the mainland. Judging from their topography, and the apparent genetic relationships of those of the northern group, the forms then existing probably included all the present islands, except San Nicolas and San Clemente. The latter appears not to have been elevated till the close of the post-Miocene period, or early in the Pliocene depression, and it is probable that the elevation of San Nicolas occurred at about the same time. The disturbance at this time seems to have been general for this whole region, including both faulting and folding, and leading not only to the differentiation of these two islands, but also, probably, to a greater elevation of all the other islands. Although the forces operative in these movements are believed to have acted intermittently from that time to the present, it is thought that they were mainly effective then; and that any later movements have been of minor importance in relation to the general movements of the California coast, since the highest elevated terraces of San Clemente and the leveled summits of Santa Cataline and Santa Rosa still closely correspond in altitude with the highest terraces on the mainland, and, going farther north, with the upper limit of the Pliocene delta deposits along the Tres Pinos Creek.

The post-Miocene elevation of the coast was followed by the Pliocene depression, during which the sea stood for a long time some 1500 feet below [above ?] its present level as shown by the highest terraces, the planation of the island summits, and the delta deposits just referred to. Whether this was the full extent of this depression for the southern coast cannot be stated from the evidence at present available. During this depression, at first Santa Cataline, San Clemente, San Pedro Hill, Santa Cruz, and Santa Rosa, all probably existed as islands; or, in the case of Santa Cruz and Santa Cataline, as two or more small islands. At this level the ocean remained, cutting away the tops of these islands, till in the case of San Pedro Hill, and perhaps of Santa Rosa also, they were probably wholly truncated, leaving submarine banks like those of the region today. It is possible that San Nicolas was also above sea level at that time, and has since been planed off to its present lower level. Of San Clemente there remained a small nucleus, near the center of the northern half of the island. Santa Cataline was reduced to a small island lying to the north of the center of the present larger division of the island, with probably one or more distant rocks, or smaller islands, toward the present extremities of the island. Santa Cruz, at that time probably existed as a single narrow island, or a line of islands, with a length of at least seven miles, and formed from the northern ridge of the western or main division of the present island. Then, as now, Santa Cruz was probably the highest, if not the largest, of the existing islands.

This depression was followed by a post-Pliocene elevation, as shown both by the present elevation of the Pliocene deposits, and by the elevated coastal

terraces. . . . . The writer is inclined, from present information, to the view of one general elevation of the California coast in post-Pliocene times, accompanied by minor oscillations, and by local differential movements, such as that called for, for example, in the formation of San Francisco Bay. . . . .

It is probable that while the oscillations of post-Pliocene times have been sufficient to connect the northern islands with the mainland, none of the southern islands have had such connection since the post-Miocene period of erosion.

The most recent movement of the coast, as indicated by drowned valleys and submarine features, is a comparatively slight depression, the evidence for which, on the southern California coast, has already been given in detail. The later history of the coast seems, therefore, to be most satisfactorily summed up in a single post-Pliocene elevation, interrupted by minor reverse movements, of which this most recent depression is probably one.

Whether or not future investigation shall lead to modification of the details of the coastal movements as here outlined, is immaterial to the main conclusions of the present paper; the principal point which it aims to establish being the fact that the latest general movements of the islands and coastline of southern California have been the same. R. D. S.

CORRECTION.

In Professor Spurr's article on "Succession and Relation of Lavas in the Great Basin Region," in the last number of the JOURNAL, the caption of the table opposite page 642 should read: "Provisional Correlation of Tertiary Lavas in the Great Basin," not "Great Britain."

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